User Manual

OKULIX

Ray-Tracing-Calculation

for the Pseudophakic Eye

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Contents

Chapter 1

Principles, Application, CE-Conformity, Product Safety

OKULIX is a program for the calculation of the optical properties of the human eye. The *designated use* in the sense of the European Medical Device Regulations is the power selection of intraocular lenses (IOL). Users of OKULIX are ophthalmologists. Other applications are not conform with the product designation.

Severe adverse events with this product shall be reported to the appropriate authority of the EU country in which the user of the product or the patient affected from this event is resident.

OKULIX complies with the requirements of the European Medical Device Regulations (EU) 2017/745 as a class I medical product.

1.1 Ray-Tracing

OKULIX is a program package which calculates single rays *exactly*. The visual impression of extended objects (e.g. Landolt's rings) can be simulated by the superposition of many rays. Diffraction from the pupil aperture is taken into account additionally [10]. *Exactly* in this context means, that the refraction of rays at each optical surface is calculated using Snell's law. For a single ray passing multiple surfaces the calculation cannot be performed by analytical formulae, because otherways so-called "transcendental equations" occur which are unsolvable for principal mathematical reasons. Instead of an analytical calculation the problem therefore has to be solved by numerical methods requiring a computer. In former times, when computers where not available, approximations have been used under which Gaussian optics is best known [4]. In this approximation, the sine in Snell's law is substituted by the arc: $sin(\alpha) \approx \alpha$ This, however, is sufficiently accurate only for very small angles, i.e., close to the optical axis. Gaussian optics therefore is also called "paraxial optics". In contrast, the calculation error inside OKULIX is the same for all distances to the optical axis (residual error $\leq$0.001D).

In all OKULIX calculations the *refraction error* is minimized. The definition of refraction- and wavefront errors is shown in fig.1.1.

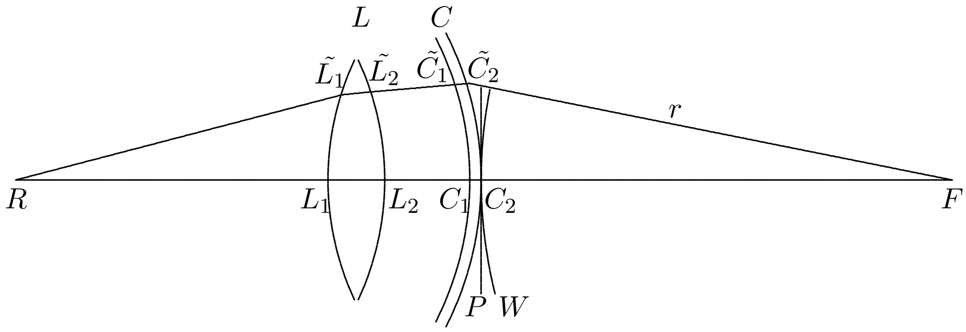

Figure 1.1: **Refraction- and Wavefront Errors**
A schematic cross-section of the eye is shown with lens L and cornea C, the optical axis from central retina R to the intersection point F with the off-axis ray r. Wavefront differences are calculated as differences between the optical path lengths of $(R, L_1, L_2, C_1, C_2, F)$ and $(R, \tilde{L}_1, \tilde{L}_2, \tilde{C}_1, \tilde{C}_2, F)$. The optical path lengths are the sums over the products of the geometrical lengths and the corresponding refractive indices. The difference between the spherical wave W starting from F and the plane wave P along r has to be added to the path length of r if F is not at infinite distance. The meridional refraction error of r is by definition the reciprocal of the distance from C_2 to F. The deviation of the ray perpendicular to the graphics plane is described by the azimuthal refraction component. All optical path lengths are calculated in three dimensions. In case of a decentered IOL the bended ray through central retina and central cornea is calculated first and then used as reference instead of the optical axis.

1.2 IOL Power Calculation

OKULIX is particularly suited for intraocular lens (IOL) calculation [11, 12, 18, 17, 19]. Axial lengths can be entered either manually or by a computer link to the measuring device. Interfaces exist to the ultrasound- and to the optical devices from Tomey, to the Haag-Streit Lenstar, the Oculus Pentacam and, via this, the optical and acoustical devices from Nidek. Also, the Tracey iTrace, the Ziemer Galilei G6 and the Heidelberg Engineering Anterion can be used. Other links are in preparation. It should be kept in mind that OKULIX uses *optical* lengths, not *acoustical* ones. Measuring devices may produce values with a systematic bias. Therefore, the values from different devices have to be transformed. The transformation is based on comparing measurements with artificial eyes or on the outcome of patient's prediction errors. Also other devices which cannot be directly connected such as the IOLMaster (Zeiss) are included, thus allowing their use at least for manual data input.

1.2.1 IOL Data

The program package includes a compilation of the mostly implanted IOL of the marked leaders. This data base is permanently actualized. In this data base, an IOL is represented *formally* by it's type and power (in D). For the calculation inside OKULIX, the IOL is *physically* characterized by the curvature radii, the refractive index, the asphericity and the central thickness. This is necessary in order to utilize the higher calculation accuracy (compared to all “formulae”), because the optical properties of an eye with a specific IOL is not unambiguously characterized only by the refractive power, which, in addition, is only well defined in the terminology of Gaussian optics.

Some IOL manufacturers additionally inform about a power offset between nominal and labeled IOL power which is additionally taken into account in OKULIX.

1.2.2 IOL Position

Postoperative IOL position can principally not be exactly calculated from the data of preoperative measurements, because it depends on the individual shrinkage of the capsular bag. *IOL position* here is defined as the distance between posterior corneal and anterior IOL surface, i.e. the postoperative anterior chamber depth (ACD). The *most probable* IOL position is predicted in OKULIX from the available preoperative measurements of axial length and of position and thickness of the crystalline lens (when measured) in the sense of a model calculation. In addition the user can enter the postoperative ACD manually in case there is a good reason for this IOL position, e.g. the measured IOL position of the already operated fellow eye. The ACD in a mean-sized eye is shown in tab.1.1 for each IOL model.

1.2.3 Spherical Aberration

Spherical aberration of the human eye mostly causes a myopisation, increasing with pupil width. Among others, it depends on the asphericity of the cornea, the asphericity of the IOL and the ratio of the IOL curvature radii called “shape factor”. All these influences are exactly taken into account in OKULIX. They can be best graphically visualized with the simulated Landolt’s rings. In order to obtain at least an estimate of the amount of the effect, the refraction deficit of an IOL is given not only paraxially, but also for the “best focus” for a pupil width of 2.5mm. OKULIX uses the *true* pupil width whereas pupillometers mostly give a value which is about 16% larger due to corneal magnification. The said pupil width can be modified by the user.

1.2.4 Phakic Intraokular Lenses

Also phakic IOL can be calculated with OKULIX. To do so, preoperative refraction must be known in addition to phakic anterior chamber depth and axial length.

The IOL proposed by OKULIX is displayed in a scaled drawing of the anterior eye segment. The user can modify the position (ACD) of the IOL thus causing a variation of the best fitting power.

If IOL primarily intended as anterior chamber IOL are to be calculated for aphakic eyes, the corresponding button has to be activated in OKULIX.

In addition, anterior and posterior surfaces of the IOL may be exchanged by one another. I this case the button IOL reverse has to be activated.

1.2.5 Toric IOL

So-called "toric IOL" for the correction of the corneal astigmatism can be selected in OKULIX in the same way as rotationally symmetric IOL. The best and safest approach is using the tomography of the eye. The mark on the IOL defining the meridian of lowest refractive power has to be aligned with the corneal meridian of highest refractive power shown in red in the OKULIX tomography.

In case of phakic, toric IOL also subjective or objective refraction can be used if the astigmatism of the crystalline lens is to be corrected in addition.

1.2.6 Additional IOL (piggyback IOL)

For the correction of a residual refraction error after cataract surgery an additional piggyback IOL can be implanted into the ciliary sulcus or into the anterior chamber. In OKULIX first the posterior chamber IOL for implantation into the capsular bag can be calculated as usual. If after that an IOL model for sulcus- or anterior chamber implantation is selected, the input window shows an additional, already activated option, the "pseudophakic IOL=" followed by the information of the IOL already implanted. After entering the eye's refraction error the optical system is now overdetermined. For this reason the axial eye length is adjusted to re-establish data consistence. After that the interactive graphical window as described in the section for phakic IOL appears.

Additional IOL can also be implanted into pseudophakic eyes when the eye shall receive an endotamponade with silicon oil, in order to compensate for the optical impact of the silicon oil. The additional IOL will be explanted later together with the silicon iol removal. For the calculation of such IOL in OKULIX the refractive index of the vitreous is replaced by the value of the used silicon oil.

		$\oslash_{Opt}$	sph	ast	n	ACD$_O$
○	Aaren: EC-1/Y/HPI	5.00	+4.0/+34.0		1.489	3.51
○	Aivimed: HPA201	6.0	1.0/+40.0		1.510	3.88
○	Aivimed: HPM404	6.0	10.0/+25.0		1.510	4.20
○	Aivimed: HPS101	6.0	1.0/+40.0		1.510	4.20
○	Aivimed: A32/G32	6.0	6.0/+30.0		1.457	3.37
○	AJL: A601250	6.00	+6.0/+30.0		1.495	2.57
○	AJL: F601250	6.00	-10.0/+40.0		1.462	3.46
○	AJL: LLASHP60	6.00	-10.0/+40.0		1.485	4.48
○	AJL: P651300	6.00	-10.0/+40.0		1.492	3.80
○	AJL: Y601075	6.00	-10.0/+40.0		1.462	3.48
○	Alcon: LX90BD	5.75	+10.0/+30.0		1.491	4.29
○	Alcon: MA30BA	5.50	+10.0/+30.0		1.5542	4.29
○	Alcon: MA50BM	6.50	+6.0/+30.0		1.5542	4.26
○	Alcon: MA60AC	6.00	+6.0/+30.0		1.5542	4.35
○	Alcon: MA60BM/MA60MA	6.00	-5.0/+30.0		1.5542	4.35
○	Alcon: MZ30BD	5.50	+10.0/+30.0		1.491	4.25
○	Alcon: MZ40BD	5.00	+10.0/+30.0		1.491	4.33
○	Alcon: MZ60BD	6.00	+10.0/+30.0		1.491	4.16
○	Alcon: SA30AT	5.50	+10.0/+30.0		1.5542	4.36
○	Alcon: SA30AL	5.50	+6.0/+34.0		1.5542	4.20
○	Alcon: SA60AT/SN60AT	6.00	+6.0/+40.0		1.5542	4.22
○	Alcon: SN60TT	6.00	+6.0/+40.0	1.5/0.75/6.0	1.5542	4.22
○	Alcon: SN60WF	6.00	+6.0/+30.0		1.5542	4.23
○	Alcon: SN6ATT IQ toric	6.00	+6.0/+34.0	1.0/0.75/6.0	1.5542	4.23
○	Alcon: SN6AD1 Restor +3	6.00	+6.0/+34.0		1.5542	4.19
○	Alcon: MN6AD1 Restor MP +3	6.00	+6.0/+34.0		1.5542	4.19
○	Alcon: SV25T0 Restor +2.5	6.00	+6.0/+34.0		1.5542	4.19
○	Alcon: SND1TT Restor toric +3	6.00	+6.0/+34.0	1.0/0.75/3.0	1.5542	4.23
○	Alcon: SV25TT Restor toric +2.5	6.00	+6.0/+34.0	1.0/0.75/3.0	1.5542	4.23
○	Alcon: TFNT00 PanOptix	6.00	+6.0/+34.0		1.5542	4.19
○	Alcon: TFNTT PanOptix toric	6.00	+6.0/+34.0	1.0/0.75/3.75	1.5542	4.23
○	Alcon: CLAREON SY60WF	6.00	+6.0/+30.0		1.5476	4.22
○	Alcon: CLAREON toric CNW0T2-9	6.00	+6.0/+30.0	1.0/0.75/6.0	1.5476	4.22
○	Alcon: CLAREON PanOptix CNWTT0	6.00	+6.0/+34.0		1.5476	4.22
○	Alcon: CLAREON PanOptix toric	6.00	+6.0/+34.0	1.0/0.75/6.0	1.5476	4.22
○	Alcon: VIVITY DFT015	6.00	+10.0/+30.0		1.5542	4.23
○	Alcon: VIVITY toric DFT215-615	6.00	+10.0/+30.0	1.0/0.75/3.75	1.5542	4.23
○	Appasamy: Supra Phob	6.00	10.0/+30.0		1.491	3.40
○	AST: Asqelio EDOF toric	6.00	0.0/+40.0	0.5/0.5/6.0	1.497	3.90
○	AST: Asqelio trifocal	6.00	+5.0/+40.0		1.497	3.90
○	Aurolab: HP757SQ	5.75	+10.0/+30.0		1.470	3.90
○	Bausch&Lomb: enVista MX60E	6.00	0.0/+34.0		1.5340	4.43
○	Bausch&Lomb: enVista MX60T	6.00	0.0/+30.0	1.25/0.75/5.75	1.5385	4.43
○	Bausch&Lomb: MI60	6.00	0.0/+30.0		1.459	4.30
○	Bausch&Lomb: H60M	6.00	0.0/+35.0		1.4743	4.11
○	Bausch&Lomb: Soflex SE	6.00	+1.0/+30.0		1.427	3.80
○	Bausch&Lomb: Sofport AOV	6.00	+1.0/+30.0		1.427	3.82
○	Bausch&Lomb: EZE-55	5.50	+0.5/+34.0		1.493	4.11
○	Bausch&Lomb: EZE-60/P492UV	6.00	+0.5/+34.0		1.493	4.05
○	Bausch&Lomb: 88TI	6.00	+0.5/+35.0		1.493	4.00
○	Bausch&Lomb: Akreos AO	6.00	+10.0/+30.0		1.459	3.85
○	Bausch&Lomb: Akreos Disc	5.50	+10.0/+30.0		1.459	3.89
○	Bausch&Lomb: Akreos Fit	5.50	+10.0/+30.0		1.459	3.70
○	Bausch&Lomb: Akreos Adapt	5.75	+10.0/+30.0		1.459	3.75
○	Bausch&Lomb: Incise	5.50	0.0/+30.0		1.466	4.10
○	Bausch&Lomb: EyeCeeone	6.00	1.0/+30.0		1.519	4.26
○	Bausch&Lomb: EyeCee	6.00	10.0/+28.0		1.519	4.42
○	Bausch&Lomb: LuxSmart	6.00	0.0/+34.0		1.544	3.91
○	Bausch&Lomb: LuxGood	6.00	0.0/+34.0		1.544	4.34
○	Bausch&Lomb: IC-8	6.00	+15.5/+27.5		1.481	4.93

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◦	Carl Zeiss: AT Lara 829MP	6.0	-10.0/+33.0		1.46	3.43
◦	Carl Zeiss: AT Lara toric929MP	6.0	-9.5/+38.0	1.0/0.5/12.0	1.46	3.43
◦	Carl Zeiss: AT Lisa 809M	6.00	0.0/+32.0		1.460	4.15
◦	Carl Zeiss: AT Lisa 909M toric	6.00	-10.0/+32.0	1.0/0.5/12.0	1.460	3.87
◦	Carl Zeiss: AT Lisa 839M	6.00	0.0/+32.0		1.460	3.60
◦	Carl Zeiss: AT Lisa Tri tor949	6.0	-5.0/+35.0	1.0/0.5/4.0	1.46	3.49
◦	Carl Zeiss: AT Torbi719M	6.0	-4.0/+32.0	1.0/0.5/12.0	1.46	3.48
◦	Carl Zeiss: CT 47S	6.00	0.0/+40.0		1.460	4.05
◦	Carl Zeiss: CT Asphina 404	6.00	-10.0/+42.0		1.460	3.75
◦	Carl Zeiss: CT Asphina 409M	6.00	0.0/+32.0		1.460	4.09
◦	Carl Zeiss: CT Asphina 509M	6.00	0.0/+32.0		1.460	4.15
◦	Carl Zeiss: CT Lucia 202(EC-3)	6.0	4.0/+34.0		1.489	3.56
◦	Carl Zeiss: CT Lucia 221	6.0	-1.0/+31.0		1.489	4.67
◦	Carl Zeiss: CT Lucia 602	6.0	4.0/+34.0		1.489	3.33
◦	Carl Zeiss: CT Lucia 621	6.0	-1.0/+35.0		1.489	4.56
◦	Carl Zeiss: CT Spheris203/P	6.00	+8.0/+30.0		1.4565	3.32
◦	Carl Zeiss: CT Spheris 204	6.00	-10.0/+45.0		1.460	3.75
◦	Carl Zeiss: CT Spheris 209M	6.00	0.0/+30.0		1.460	4.07
◦	Corneal: ACR6DSE	6.00	+10.0/+30.0		1.465	4.46
◦	Corneal: Ultima	6.00	+10.0/+30.0		1.465	3.03
◦	Corneal: A6	6.00	+10.0/+30.0		1.465	4.42
◦	Corneal: Concept360	6.00	+10.0/+30.0		1.465	4.96
◦	Cristalens: Artis	6.00	+10.0/+30.0		1.5422	4.40
◦	Cristalens: Luxiol Y	6.25	+10.0/+30.0		1.5422	4.40
◦	CROMA: NZ-1	6.00	1.0/+30.0		1.519	4.42
◦	Curamed: AS695CA	6.00	+10.0/+30.0		1.460	3.95
◦	Curamed: AS695PA	6.00	+10.0/+30.0		1.460	3.95
◦	Curamed: HD600Y-A	6.00	+10.0/+30.0		1.460	3.95
◦	Curamed: HD600Y	6.00	+10.0/+30.0		1.460	3.95
◦	Curamed: SA60CZ-YA	6.00	+10.0/+30.0		1.460	3.95
◦	Curamed: HD700Y-A	6.00	+10.0/+30.0		1.460	3.95
◦	Curamed: HD700Y	6.00	+10.0/+30.0		1.460	3.95
◦	Curamed: PL600	6.00	+10.0/+30.0		1.460	3.95
◦	Curamed: SA60CZ	6.00	+10.0/+30.0		1.460	3.95
◦	Curamed: SA60CZA	6.00	+10.0/+30.0		1.460	3.95
◦	Curamed: SA700	6.00	+10.0/+30.0		1.460	3.95
◦	Curamed: HB-60/HY-60	6.00	+10.0/+30.0		1.540	3.60
◦	EYEOL UK: Ultima/Gold	6.00	+1.0/+35.0		1.465	4.1
◦	EYEOL UK: Hyflex	6.00	+10.0/+30.0		1.502	4.18
◦	EYEOL UK: Hyflex EC	6.00	+10.0/+30.0		1.540	4.23
◦	HOYA: YA-60BB	6.00	-7.0/+40.0		1.516	4.10
◦	HOYA: YA-65BB	6.50	+4.0/+40.0		1.516	4.09
◦	HOYA: VA-60BBR/PC-60R	6.00	+4.0/+40.0		1.517	4.07
◦	HOYA: YA-60BBR/PY-60R	6.00	+4.0/+40.0		1.516	4.07
◦	HOYA: FY-60AD/PY-60AD	6.00	+4.0/+30.0		1.516	4.08
◦	HOYA: FC-60AD/PC-60AD	6.00	+4.0/+30.0		1.517	4.08
◦	HOYA: NY-60/250/251	6.00	+6.0/+30.0		1.516	3.97
◦	HOYA: 351	6.00	+10.0/+30.0	1.5/0.75/6.0	1.516	4.15
◦	HOYA: iSert 254 (clear)	6.00	+6.0/+30.0		1.517	4.15
◦	HOYA: iSert 255 (yellow)	6.00	+6.0/+30.0		1.516	4.15
◦	HOYA: Vivinex iSert XY1/XC1	6.00	+6.0/+30.0		1.544	4.40
◦	HOYA: iSert 150	6.00	+6.0/+30.0		1.517	4.15
◦	HOYA: iSert 151 (yellow)	6.00	+6.0/+30.0		1.516	4.15
◦	HOYA: Vivinex toric XY1A	6.00	+6.0/+30.0	1.0/0.75/6.0	1.544	4.20
◦	HOYA: Vivinex Gemetric XY1 GP	6.00	+10.0/+30.0		1.544	4.15
◦	HOYA: Vivinex Gemetric XY1 GPTB	6.00	+10.0/+30.0	1.0/0.75/3.75	4.05	
◦	HOYA: Vivinex Impress XY1	6.00	+6.00/+30.0		1.544	4.15
◦	HumanOptics: AS	5.75	0.0/+30.0		1.4611	3.60
◦	HumanOptics: Aspira-aA(Y)	6.00	-20.0/+60.0		1.4611	3.57
◦	HumanOptics: Torica-aA(Y)	6.00	-20.0/+40.0	1.0/0.5/20.0	1.4611	3.57
◦	HumanOptics: Aspira-aXA(Y)	7.00	-10.0/+30.0		1.4611	3.98
◦	HumanOptics: Triva-aAY	6.00	10.0/+30.0		1.4611	3.86
◦	HumanOptics: Triva T-aAY	6.00	10.0/+30.0	1.0/0.5/6.0	1.4611	3.86

		$\oslash_{Opt}$	sph	ast	n	ACD_O
○	i-Medical: Accurate	6.00	+1.0/+35.0		1.465	4.1
○	IOL Expert: PCX81NY / PCM81NY	6.00	10.0/+30.0		1.461	3.33
○	IOL Expert: PCX81NY T0-T6	6.00	10.0/+30.0	0.75/0.75/5.25	1.461	3.33
○	IOL Expert: PCM81NY T0-T3	6.00	10.0/+30.0	0.75/0.75/3.00	1.461	3.33
○	J&J: Sensar AR40e	6.00	-10.0/+30.0		1.47	3.95
○	J&J: Sensar AAB00	6.00	6.0/+30.0		1.47	4.10
○	J&J: VERISYSE 50	5.00	-23.5/+12.0		1.492	2.5
○	J&J: VERISYSE Aphakia	5.00	+10.0/+30.0		1.492	2.5
○	J&J: VERISYSE 60	6.00	-15.0/-3.0		1.492	2.5
○	J&J: VERIFLEX	6.00	-14.5/-2.0		1.43	2.5
○	J&J: 757C	6.50	-10.0/+7.0		1.491	3.50
○	J&J: Tecnis Z9000/ZM001/ZM900	6.00	+5.0/+30.0		1.458	3.90
○	J&J: Tecnis CL Z9002	6.00	+5.0/+30.0		1.460	3.90
○	J&J: Tecnis ZA9003/ZMA00	6.00	+10.0/+30.0		1.47	3.90
○	J&J: Tecnis ZCB00/ZMB00/ZLB00	6.00	+5.0/+34.0		1.47	4.50
○	J&J: Tecnis ZXR00/Symfony	6.00	+5.0/+34.0		1.47	4.50
○	J&J: Tecnis ZMT/Symfony T	6.00	+5.0/+34.0	1.0/0.75/4.0	1.47	4.50
○	J&J: Tecnis ZCU toric II	6.00	+5.0/+34.0	1.0/0.75/8.0	1.47	4.50
○	J&J: HSM60	6.00	+4.0/+34.0		1.492	4.19
○	J&J: AC60/AC51L	6.00	+8.0/+30.5		1.492	2.5
○	J&J: Eyhance	6.00	+5.0/+34.0		1.47	4.50
○	Kowa: Avansee Preload1P	6.00	+6.0/+30.0		1.52	4.10
○	Kowa: AvanseePreset (3P)	6.00	+6.0/+26.0		1.52	4.10
○	Kowa: Avansee Preload1P Toric	6.00	+6.0/+26.0	0.75/0.75/6.0	1.52	4.10
○	Lenstec: Softec 1	5.75	-5.0/+47.0		1.46	3.50
○	Lenstec: Softec HD	5.75	5.0/+36.0		1.46	3.40
○	MBI: 302AC/P302AC,302A/P302A	6.00	0.0/31.0		1.497	4.1
○	MBI: PM302AC/PM302A	6.00	0.0/31.0		1.497	4.1
○	MBI: PT302AC/PT302A	6.00	0.0/+30.0	1.0/0.5/6.0	1.497	4.1
○	MBI: 300AC/300A	6.00	0.0/31.0		1.497	4.1
○	Medicontur: 610/611/612HPS	6.00	+0.0/+30.0		1.4595	3.78
○	Medicontur: 640P/Y	6.00	-10.0/+35.0		1.4694	3.84
○	Medicontur: 640AB/Y	6.00	0.0/+45.0		1.4610	3.33
○	Medicontur: 640/677MY	6.00	0.0/+35.0		1.4610	3.85
○	Medicontur: 677AB/Y	6.00	-10.0/+45.0		1.4610	3.33
○	Medicontur: 677P/Y	6.00	-10.0/+35.0		1.4694	3.84
○	Medicontur: 677TA/Y	6.00	-10.0/+35.0	1.0/0.75/10.0	1.4610	3.84
○	Medicontur: 877PA/FAB/Y/Elon	6.00	-10.0/+35.0		1.4648	3.95
○	Morcher: 46G	6.00	+8.5/+35.0		1.465	4.11
○	Morcher: 89A	5.00	+8.5/+35.0		1.465	4.07
○	Morcher: 92B	6.50	+8.5/+30.0		1.465	4.05
○	Morcher: 92S	5.50	+8.5/+35.0		1.465	4.19
○	Morcher: 92C	5.50	+8.5/+35.0		1.465	4.16

		$\oslash_{Opt}$	sph	ast	n	ACD_O
○	MTO: Crystal Evolution	6.00	7.0/+30.0		1.491	4.05
○	NIDEK: NX-1/NZ-1	6.00	10.0/+28.0		1.519	4.42
○	NIDEK: N4-11YB	6.00	1.0/+30.0		1.519	4.24
○	NIDEK: N4-18B	6.00	1.0/+30.0		1.519	4.17
○	NIDEK: N4-18YG	6.00	1.0/+30.0		1.519	4.24
○	NIDEK: NS-60G/NS-60YG	6.00	1.0/+30.0		1.519	4.26
○	Ophthalmo Pro: AC7013	6.00	+0.5/+34.0		1.460	3.96
○	OPHTEC: ARTISAN 50	5.00	-23.5/+12.0		1.492	2.5
○	OPHTEC: ARTISAN 50 T	5.00	-23.5/+12.0	2.0/0.5/7.5	1.492	2.5
○	OPHTEC: ARTISAN Aphakia	5.00	+10.0/+30.0		1.492	2.5
○	OPHTEC: ARTISAN 60	6.00	-15.0/-3.0		1.492	2.5
○	OPHTEC: ARTIFLEX	6.00	-14.5/-2.0		1.43	2.5
○	OPHTEC: ARTIFLEX T	6.00	-13.5/-2.0	1.0/0.5/5.0	1.43	2.5
○	OPHTEC: PC545 QuadrimaX	6.00	5.0/+35.0		1.462	3.51
○	OPHTEC: Precizon 560	6.00	-10.0/+35.0		1.462	3.65
○	OPHTEC: Precizon 570 NVA	6.00	1.0/+35.0		1.462	3.65
○	OPHTEC: Precizon 565 toric	6.00	1.0/+34.0	1.0/0.5/10.0	1.462	3.65
○	OPHTEC: Precizon 575 NVA toric	6.00	5.0/+34.0	1.0/0.5/6.0	1.462	3.65
○	OPHTEC: Precizon go 580	6.00	-10.00/+35.0		1.462	3.65
○	PD: Domicryl S	6.00	-5.0/+36.0		1.459	4.05
○	PD: Domicryl Biflex 677T/TY	6.00	+2.0/+45.0	1.5/0.75/9.00	1.4611	3.80
○	PD: Domicryl Biflex HL/HLY	6.00	-10.0/+35.0		1.4611	3.31
○	PD: Polylens Y51 TP	6.00	+10.0/+30.0	1.5/0.75/6.0	1.516	4.15
○	PD: Polylens H50P/Y50P	6.00	+6.0/+30.0		1.516	3.97
○	PD: Polylens H60P/Y60P	6.00	+6.0/+30.0		1.516	4.10
○	PD: Nexload-System NZ1	6.00	+10.0/+28.0		1.519	4.42
○	PD: Nex Acri	6.00	+1.0/+30.0		1.519	4.17
○	PD: Nex Acri AA Aktis	6.00	+1.00/+30.0		1.519	4.24
○	PD: Aktis SP/SPY	6.00	+1.0/+30.0		1.519	4.26
○	PD: Nexload-System SZ1	6.00	+11.0/+30.0		1.519	4.26
○	PD: Polylens A61/Biovue	6.00	+0.5/+34.0		1.46	3.96
○	PD: H10/Y10	5.00	+4.0/+34.0		1.489	3.50
○	PD: H30/Y30	6.00	+4.0/+34.0		1.489	3.55
○	PD: Polytech Y35	6.50	+4.0/+34.0		1.489	3.55
○	PD: Polylens AS66/AS66-Y	6.00	+5.0/+36.0		1.4614	3.70
○	PD: Aurium 404	6.00	+1.0/+34.0		1.49	4.22
○	PhysIOL: Micro F / Mic-F	6.15	0.0/+35.0		1.462	3.74
○	PhysIOL: Pod F	6.0	0.0/+35.0		1.462	3.84
○	PhysIOL: Pod FT	6.0	+6.0/+35.0	1.0/0.75/6.0	1.462	3.92
○	PhysIOL: PODT / Ankoris	6.0	+10.0/+30.0	1.5/0.75/6.0	1.462	3.78
○	PhysIOL: PodEye / Podagf	6.0	0.0/+35.0		1.536	4.20
○	PhysIOL: Slimflex	6.0	0.0/+30.0		1.462	3.81
○	PhysIOL: Micro+ / Mic-26P	6.15	-10.0/+35.0		1.462	3.89
○	PhysIOL: Micropure / Micagf	6.0	-10.0/+35.0		1.536	4.24

		$\oslash_{Opt}$	sph	ast	n	ACD_O
○	Rayner: RayOne RAO100C	6.00	-10.0/34.0		1.460	3.86
○	Rayner: C-flex 570C	5.75	8.0/34.0		1.460	3.63
○	Rayner: T-flex 573T	5.75	20.0/34.0	1.0/0.5/11.0	1.460	3.63
○	Rayner: RayOne RAO600C	6.00	-10.0/34.0		1.460	3.83
○	Rayner: RayOne RAO603F	6.00	0.0/30.0		1.460	3.83
○	Rayner: RayOne toric RAO610T	6.00	-9.5/34.0	1.0/0.5/11.0	1.460	3.83
○	Rayner: RayOne toric RAO613Z	6.00	6.0/30.0	0.75/0.75/4.5	1.460	3.83
○	Rayner: Superflex 620H	6.25	-10.0/25.0		1.460	3.87
○	Rayner: T-flex 623T	6.25	-10.0/25.0	1.0/0.5/11.0	1.460	3.87
○	Rayner: Sulcoflex 653L	6.50	-10.0/10.0		1.460	3.10
○	Rayner: Sulcoflex 653T	6.50	-7.0/7.5	1.0/0.5/11.0	1.460	3.10
○	Rayner: Sulcoflex 703F	6.00	-3.0/3.0		1.460	3.10
○	Rayner: RayOne RAO800C	6.00	-10.0/32.0		1.506	4.07
○	Rayner: Superflex 920H	6.25	-10.0/22.0		1.460	3.87
○	Rayner: C-flex 970C	5.75	8.0/34.0		1.460	3.91
○	Rayner: RayOne EMV RAO200E	6.00	10.0/30.0	0.75/0.75/4.5	1.460	3.78
○	Rayner: RayOne EMV toric	6.00	10.0/25.0		1.460	3.78
○	Ruck: 618/618Y	5.90	0.0/+35.5		1.457	4.07
○	Santen: natural NX-60	6.00	+10.0/+30.0		1.540	4.10
○	Santen: natural NX-70	6.00	+10.0/+30.0		1.540	3.90
○	Santen: natural W-60	6.00	+10.0/+30.0		1.540	4.20
○	Santen: natural X-60	6.00	+10.0/+30.0		1.540	4.10
○	Santen: natural X-70	6.00	+10.0/+30.0		1.540	3.90
○	Staar: CC420BF	6.00	11.0/+33.0		1.442	3.95
○	Staar: KS-3AI	5.60	12.5/+28.5		1.413	4.02
○	Staar: KS-X/KS-Xs	6.00	10.0/+28.0		1.519	4.42
○	Staar: Evo Visian ICL/V4C	6.00	-18.0/+16.5		1.4415	3.10
○	Staar: toric ICL V4C	6.00	-17.5/+16.5	0.5/0.5/4.5	1.4415	3.10
○	Staar: KS-1	6.00	7.0/+26.0		1.413	4.27
○	Staar: KS-SP	6.00	1.0/+30.0		1.519	4.26
○	Tekia: TEK-Lens Model 411	6.00	+10.0/+30.0		1.430	3.93
○	Tekia: TEK-Lens Model 614	6.00	+10.0/+30.0		1.457	3.85
○	Teleon: L-312	6.00	0.0/+35.0		1.461	3.59
○	Teleon: L-313/LS-313MF	6.00	0.0/+35.0		1.461	3.33
○	Teleon: LS-313 T0-T6	6.00	10.0/+30.0	0.75/0.75/5.25	1.461	3.33
○	Teleon: LU-313 MFT	6.00	0.0/+36.0	0.25/0.75/10.0	1.461	3.33
○	Teleon: Acunex AN6Q	6.00	10.0/30.0		1.54	4.22
○	Teleon: Acunex AN6V/AN6VM	6.00	10.0/30.0		1.54	4.22
○	Teleon: Acunex AN6V/AN6VM tor	6.00	10.0/30.0	0.75/0.75/3.0	1.54	4.22
○	VSY: Acriva UD/UDM 611/613/625	6.00	+0.0/+45.0		1.4618	3.31
○	VSY: REVIOL MF/MFM 611/613/625	6.00	+0.0/+45.0		1.4618	3.31
○	VSY: Acriva toric UDM 611	6.00	+0.0/+45.0	1.0/0.5/12.0	1.4618	3.31
○	VSY: REVIOL toric MFM 611	6.00	+0.0/+45.0	1.0/0.5/12.0	1.4618	3.31
○	Xclens: Idea	6.00	-10.0/+43.0		1.461	4.03
○	Xcelens: Classica	6.00	0.0/+30.0		1.461	4.03
○	1STQ: Basis Q - B2AWxx	6.00	-10.0/35.0		1.4610	3.84
○	1STQ: Basis Q - B2APxx	6.00	0.0/35.0		1.4610	3.84
○	1STQ: Basis Q - B1EWYM/B2EWYM	6.00	0.0/35.0		1.4610	3.85
○	1STQ: Basis Z- B1AWxx	6.00	-10.0/35.0		1.4610	3.84
○	1STQ: Basis Z toric - B1TWxx	6.00	-10.0/35.0	1.0/0.75/10.0	1.4610	3.84
○	1STQ: Basis Z- B1ADxx/B1ABxx	6.00	-10.0/35.0		1.4694	3.95
○	1STQ: Basis K - 611HPS	6.00	0.0/35.0		1.4610	3.78
○	1STQ: V	6.00	0.0/30.0		1.497	4.10
○	1STQ: V toric	6.00	0.0/30.0	1.0/0.5/6.0	1.497	4.10
○	1STQ: Basis Z- EDOF B1XBY0	6.00	10.0/35.0		1.4648	3.95

Table 1.1: **IOL Types**

- $\oslash_{Opt}$: *optical cross diameter [mm]*
- sph: *spherical power range in diopters*
- ast: *astigmatic power range (start, steps, max.)*
- n: *index of refraction*
- ACD_O: *mean ACD value as used in OKULIX [mm]*

1.3 Corneal Topography

As an alternative to entering corneal radii by hand, they can be taken also from a two-dimensional corneal topographic mapping. OKULIX calculates the radii and the numerical eccentricity from the raw data by a three-dimensional numerical fit algorithm [13]. It should be taken into account that for the following retinal images the *real* corneal topography is used (not the fit function). This mode is indicated by a blue field "cornea active" in the upper right corner of the retinal image until this mode is deactivated again by pressing the button "cancel" in the CORNEA branch of the program.

For the user-friendly use of OKULIX in a workstation see below.

1.4 IOL Calculation after Corneal Refractive Surgery

After myopia correcting corneal refractive surgery the asphericity of the normally prolate cornea is often changed to an oblate shape. If corneal vertex radii are measured by keratometry in such cases, the resulting radii may be too small, resulting in an hyperopic outcome after cataract surgery. In OKULIX this is avoided if the corneal topography is used to extract the vertex radii [16]. No further user action is required beside loading the topography. Any other data prior to refractive surgery ("clinical history") are not needed. In most cases, it is even not necessary to know about the fact of prior refractive surgery, since all information is based on the actually measured data.

Lasik, PRK or Smile additionaly changes the ratio of anterior to posterior corneal radius. Then, the posterior radius has to be measured in addition, see next section.

1.4.1 Posterior Corneal Radius

Normally, posterior corneal vertex radii in OKULIX are calculated from anterior vertex radii. In most cases this is sufficiently accurate, because variations of posterior radii have only a small impact on overall accuracy. An error of 0.1mm in anterior corneal vertex radius causes a refractive error in corneal plane of 0.6D for a mean-sized eye, the same error in posterior corneal vertex results in 0.1D. Nevertheless, the error from posterior corneal radius may be non-negligible in cases of higher corneal ablation. Therefore, the measured average posterior corneal radius can be entered explicitely. It is directly extracted from 2-dimensional pachymetries.

The posterior corneal surface is mathematically described by the same algorithm as the anterior surface. Differences in astigmatism between anterior and posterior surface are taken into account exactly for toric IOLs.

1.5 Corneal Refractive Surgery

This part of the program is an option, i.e., it is not included in all installations. Corneal profiles can be either read in as topographic data (see previous section), or they can be generated as "model" data.

1.5.1 Corneal Model

For the corneal model, it is assumed that the cornea can be approximated by the rotation of a cartesian curve (circle, ellipsis, parabola, hyperbola), i.e. a conicoid, which is then compressed in one dimension [13]. Thereby, two different vertex radii perpendicular to each other are generated, corresponding to the axes of the classical spherocylinder. In addition, the whole three-dimensional body can be shifted in an arbitrary direction. Altogether, the cornea is defined in the model by two radii, their angle to the horizontal, the numerical eccentricity e and a shift vector. In the images shown, only the absolute value of the shift vector d is displayed. However, internally it is represented as a two-dimensional vector. If the sign of the numerical eccentricity is set negative, this has only a formal meaning (negative numerical eccentricities are mathematically nonsense). In such a case, an oblate cornea is described which is approximated by an ellipsis, for which the *minor* axis is parallel to the optical axis. The sometimes used asphericity Q can be calculated from the numerical eccentricity e by $Q = -e^2$

The corneal model defined by the parameters R_1, R_2, α, e is the "standard" within OKULIX.

A simplified possibility is given by entering the Refraction, i.e. sphere, cylinder and axis without asphericity.

If corneal topographic data are already present (either from an input file or generated as a model), another model approximation can be calculated by Zernike polynomials. This is provided particularly for didactic purposes. Zernike approximations can be calculated for different radial orders n ($3 \leq n \leq 12$). The number of series elements is then $(n+1)(n+2)/2$ e.g. 45 for the 8-th radial order.

The quality of the model approximation in a single case can be estimated by Diff. to Model. The difference between real cornea and model cornea is displayed either as a height profile or as a profile of the refraction or wavefront difference. This difference is calculated for the *unshifted* coordinates.

Chosing Difference to.. the difference between the actual cornea and another cornea, defined by its topographic data is calculated. This difference is again displayed either as height profile or as a profile of the refraction or wavefront difference.

If a model cornea is generated, the model parameters displayed after that might have little differences to the input data. This results from the fact that these parameters are always re-calculated from the two-dimensional data. The small differences mentioned show the limits of the model approximation.

Corneal thickness is internally treated as a two-dimensional data field. These data are provided and directly transferred to OKULIX by Scheimpflug- and OCT devices.

1.5.2 Calculation Method for Corneal Ablation

In the calculation of Lasik / PRK ablation profiles, in principle all refraction errors (myopia, hyperopia, astigmatism, irregular regions) can be corrected. As target profile, a spherical cornea, an aspherical cornea with user-defined numerical eccentricity or an aspherical cornea, for which numerical eccentricity is optimized in such a way, that spherical aberration of the eye is minimized, can be chosen [14]. In addition, the ablation profile can be numerically "smoothed" in order to eliminate high frequency errors.

In the calculation of ablation profiles for Lasik / PRK it is always tried to minimize the ablation depth. In case of a mixed astigmatism, the steepest meridian undergoes a myopic correction, the flattest one a hyperopic correction ("cross-cylinder ablation"). In some cases the optical outcome may be nevertheless unsatifying. This can be verified by the two-dimensional refraction map, or, better, by simulated Landolt's rings. The suboptimal outcome is caused by the primary data quality. They can either contain too many missing data points or the approximation by the model parameters is too poor.

1.6 OKULIX-Workstation

OKULIX can be either run in an arbitrary MS-WINDOWS-computer as a standalone program, or it can be integrated into a computer that controls a measuring device (topographer or biometer). The latter case is particularly user-friendly because the software of the device and OKULIX are already internally connected with each other.

1.6.1 TMS-Workstation

From summer 2006 the Tomey TMS-topographer supports direct call of and data transfer to OKULIX. When OKULIX is called, the actual topography is transferred to OKULIX, and the data extracted from it by OKULIX are directly used for IOL calculation. In OKULIX up to four IOL models are calculated simultaneously. The user has to select these IOL at start out of a list of all IOL models. This selection can be again modified at any time later. The actual topography can also be stored within the OKULIX software environment. The Tomey CASIA OCT can be used the same way.

During the OKULIX calculations started from TMS software, the TMS software must not be called a second time, as this could mix up data of different eyes.

1.6.2 Haag-Streit-Lenstar

Axial eye length, crystalline length position and thickness and keratometric data measured by Haag-Streit-Lenstar can be used in OKULIX. With the measured data of the crystalline lens the accuracy of postoperative IOL position is improved.

Note that in this case the data of both eyes (if measured) are processed immediately after one another. The combination of the Lenstar with one of the supported topographers allows a user-friendly processing of all measured data inside OKULIX.

1.6.3 Oculus Pentacam

Since May 2011, topography and spatially resolved pachymetry measured by this Scheimpflug device can be transferred to OKULIX which can be called from inside the Pentacam software.

1.6.4 Tracey iTrace

Topographies measured by this device can be transferred to OKULIX which can be called from the iTrace software from July 2013.

1.6.5 Ziemer Galilei G6

Tomographies measured by this device together with axial eye lengths and positions an thicknesses of the crystalline lens can be transferred to OKULIX which can be called from the Galilei software from Mai 2014.

1.6.6 Heidelberg Engineering Anterion

This device can be used with OKULIX from January 2019. Corneal tomography, axial eye length and position and thickness of the crystalline lens are transferred and used by OKULIX.

Chapter 2

Installation

2.1 Workstation, all devices

A "workstation" in this context is a measuring device controlled by a computer in which OKULIX is installed. The installation of the said device must be performed prior to the OKULIX installation in order to allow the recognition of the device during OKULIX installation. When the workstation comprises a topo- or tomographer and the Haag-Streit Lenstar, OKULIX combines the data of the two devices automatically. It installes itself twice in such a case, but the user does not need to take any care on this, neither during installation nor in later use.

For installation on a workstation, the USB-dongle must be plugged in, and the file SETUP-OKULIX.BAT must be double clicked on the corresponding device, see fig.2.1. Old versions are overwriten. The procedure must not be interrupted. When OKULIX is already pre-installed, this step can be skipped. Only the corresponding USB-dongle must be in place.

2.1.1 Update

If an update is required, this is possible with a new dongle. Alternatively, the file OKULIX.NEU can be copied to the dongle. It contains the update information. This file can be downloded from WWW.OKULIX.DE. There also the current version is indicated. After that, the file SETUP-OKULIX.BAT on the dongle has to be double clicked. If OKULIX.NEU is present, it is automatically used for updating on the execution of SETUP-OKULIX.BAT. The update procedure must not be interrupted.

2.1.2 Setup

In case the preset window size or language need to be modified this can be done with the setup menue shown in fig.2.2. It opens with F10 when this setup function is indicated in the header line of the active window. Here also the printout of the full refraction (in small print) can be enabled or disabled. In addition, the size of the optical zone for the extraction of global parameters and the ratio of the axial length versus crystalline lens parameters for the calculation of the most probable IOL position can

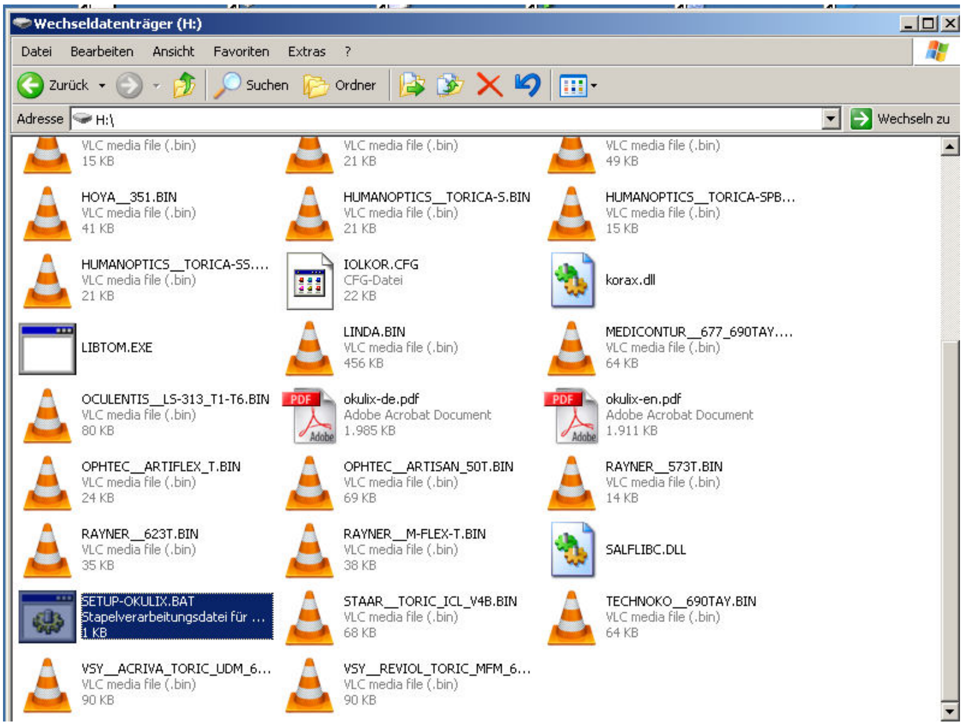


Figure 2.1: **Installation of OKULIX**
First, all other applications should be closed. Then double click to SETUP-OKULIX.BAT *which is stored on the USB memory stick. The proposed target directory has to be confirmed. Then OKULIX software is installed (10-20s). The system is ready for use now.*

be determined. Further, the character size can be adjusted to Japanese computers.

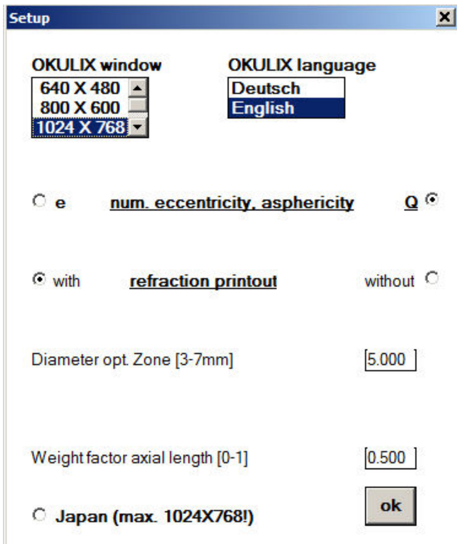


Figure 2.2: **Setup for window size and language**

In addition there is a selection if aspheric surfaces are parametrized by the numerical eccentricity e or by the asphericity $Q = -e^2$*. The printaout of the full refraction (in small) can also be enabled or disabled. Further the size of the optical zone for the determination of the global corneal parameters and the ratio of the axial length versus crystalline lens parameters for the calculation of the most probable IOL position can be defined. Also, an adjustment of the character size to Japanese computers is possible. The settings are applied after the next restart of* OKULIX*.*

2.2 Tomey TMS, Casia, OA, AL

OKULIX is already pre-installed by Tomey. The data of the optical (Tomey OA series) or acoustical (Tomey AL series) axial length measuring devices are transferred to OKULIX by the Tomey software.

2.3 Oculus Pentacam

After the OKULIX installation some settings are needed in the Pentacam software in order to transfer the measured data and automatically start OKULIX, see fig.2.3.

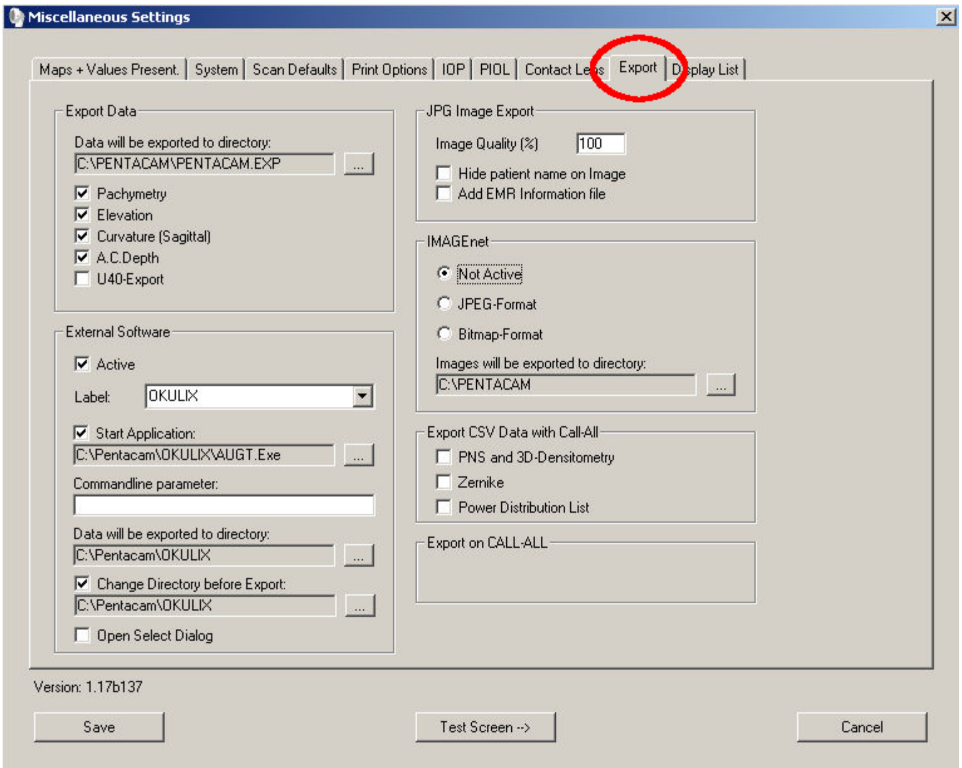


Figure 2.3: **Installation settings in Pentacam software**

- Select "Settings", "Micellaneous Settings" and "Export" in the Pentacam software.
- Write OKULIX into the next free label in the framed area "External Software" and activate the corresonding box (hook).
- Activate the field "Start Application" (hook), click on  and select C:\Pentacam\OKULIX\AUGT.EXE
- Click to the symbol  next to "Data will be exported to directory" and select C:\Pentacam\OKULIX
- Mark the box "Change directory before export" (hook)
- Use again  to select C:\Pentacam\OKULIX

- Finally click the button “save” (lower left).

2.4 Tracey iTrace

The interface is pre-installed and active.

2.5 Haag-Streit Lenstar

The installation is shown in fig.2.4.

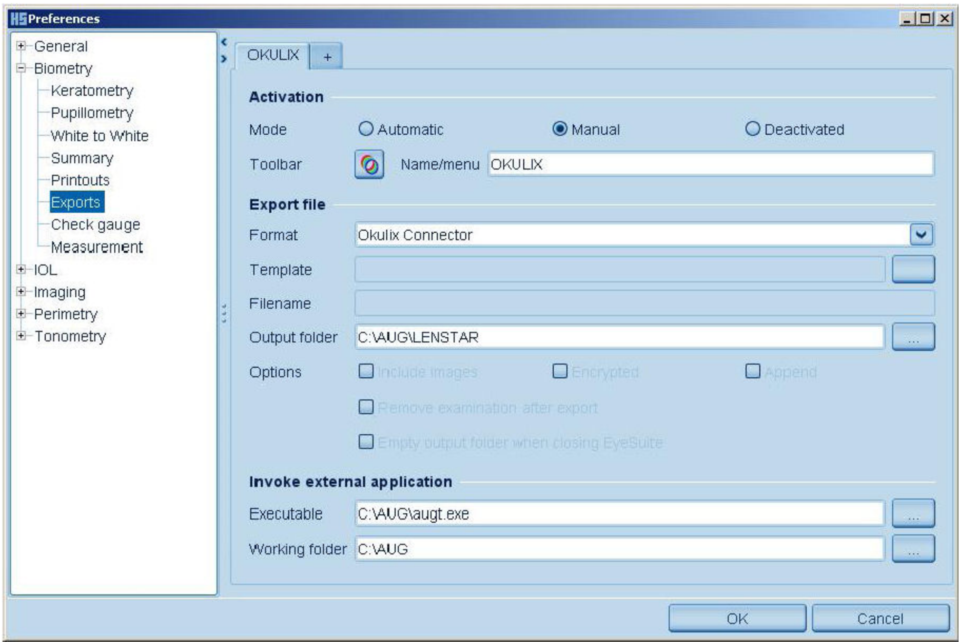


Figure 2.4: **OKULIX installation for Haag-Streit-Lenstar**
First, the OKULIX *software is to be installed as described in fig.2.1. Then, the EyeSuite software is to be prepared for export (only once) to* OKULIX*. In the caption line “Extras” must be activated, then “Settings”. After clicking the “+” next to “Biometry” click to “Exports”. In this window activate the button “Manual”, then select the “OKULIX Connector” in the item “Format” and the file OKULIX.PNG in the “Toolbar”. This icon is to be used for later IOL calculation.*

2.6 Ziemer Galilei G6

The interface is pre-installed and active.

2.7 Heidelberg Engineering Anterion

The interface is pre-installed and active.

2.8 PC Version

"PC version" (or standalone version) in this context means an OKULIX version which is not installed in the computer of a measuring device. It does not need a dongle but an installation medium containing the software.

The PC version of OKULIX can be installed and run under the operating Microsoft systems Windows95, Windows98, WindowsME, Windows-NT, Windows2000, WindowsXP, WindowsVista, Windows7 Windows10 or Windows11. Installation is only possible on a single computer, *not* in a network environment. For licence and security reasons, the installed program cannot be copied und run on another computer. In case of violation of these rules or in case of improper installation the program is finished with the message "licence ?".

For the PC-installations the following steps have to be executed:

1. Put the distribution medium into the corresponding drive and close the drive.

2. Double click to "My Computer".

3. Double click to the drive containing the OKULIX distribution medium.

4. Double click to "SETUP".

5. The proposed target directory C:\AUG has to be confirmed either by click to "OK" or by pressing the "Enter"- or "Return"-key, or another target directory has to be enterd and confirmed by OK.

6. If the corresponding window opens, the "Licence-Code" has to be entered, carefully looking to upper- and lowercase characters.

7. The following installation steps are indicated. The display may become (in part) dark for short times.

8. After the successfull installation the program is started automatically for the first time. After confirming the screen size and language the program can be finished in the next window by clicking to STOP.

9. An icon OKULIX is automatically generated on the "Desktop". If this is not the case (in a non-standard system configuration) this icon has to be generated manually following the corresponding Microsoft rules.

10. Attention: if the Windows character size differs from the default value, OKULIX buttons or input data fields may be not completely visible.

2.9 De-Installation

The installation of OKULIX does not cause any entries or modifications of the operating system of the computer. Therefore, if a de-installation is required, only the directories used by OKULIX are to be deleted. Depending on the version, these are: C:\AUG, C:\TMS\OKULIX, C:\Pentacam\OKULIX, C:\TRACEY\OKULIX, C:\GALILEI\OKULIX and C:\ANTERION\OKULIX. In addition the corresponding icon on the desktop (if any) is to be deleted.

Chapter 3

Use of the program

3.1 Workstation

In this configuration, the program needs an USB memory stick as a dongle containing the licence code and the software.

The call of OKULIX is specific in the calling software of the measuring device, however, the display of the results is always the same, see fig.3.1.

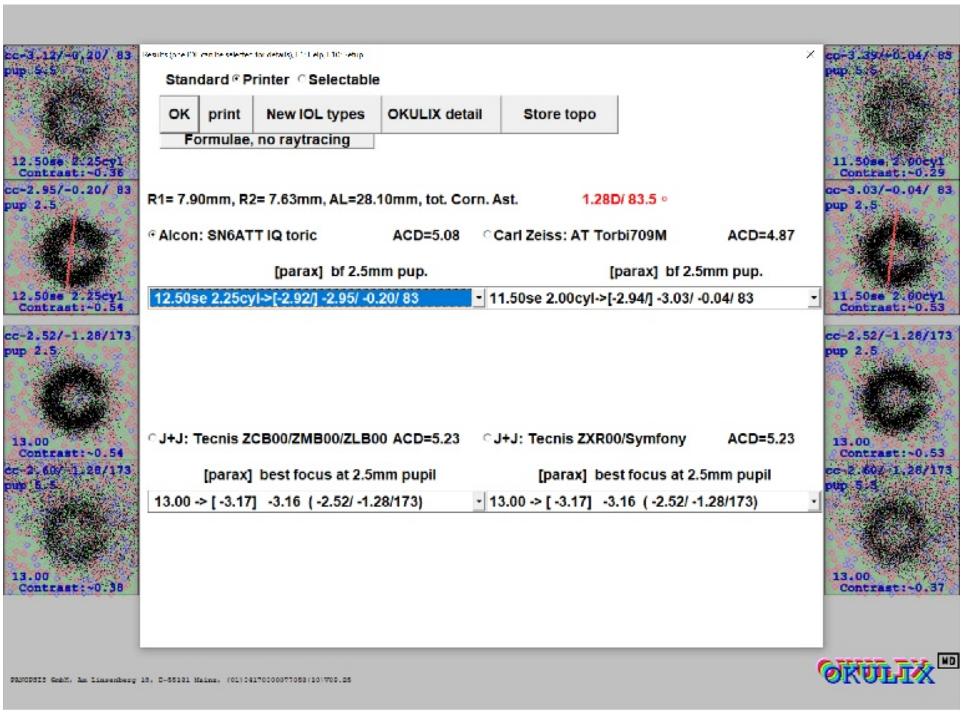


Figure 3.1: **Results of IOL Calculation**

After clicking to the OKULIX button in the software of the corresponding device the results for up to 4 IOL models are displayed, provided they had been selected before (see fig.3.3). For each IOL model the assumed postoperative position is shown (ACD=...). The refractions are calculated paraxially and for the best focus of the assumed pupil width (default: 2.5mm) in pupil plane. They can be scrolled for each power level in the sub-windows of the IOL models. The difference between paraxial and best focus refraction is a suitable measure of the spherical aberration of the eye implanted with the corresponding IOL. In rotational symmetric IOLs the spherical equivalent is shown paraxially and in the best focus; in toric IOLs, the sphere is shown, followed in both cases by cylinder value and axis.

Two Landolt rings of visual acuity chart size 1.0 (20/20, 6/6, logMar 0) are simulated, one with normal (e.g. 2.5mm) and one with maximal (5.5mm) pupil size. The simulations are calculated for best sphero-cylindrical correction which is indicated in blue on top of the image. Thus the simulated visual impressions exactly show the impact of all higher order optical aberrations. As a quantitative measure the contrast of the Landolt rings is indicated (blue).

The total corneal astigmatism, i.e. the combination of anterior and posterior astigmatism, is shown in red. The axis is additionally plotted in the Landolt ring simulations.

For the display of this output window with up to 8 Landolt rings, the window size (F10) must be set to 1280X960. This setting does not apply immediately but only after the next OKULIX call.

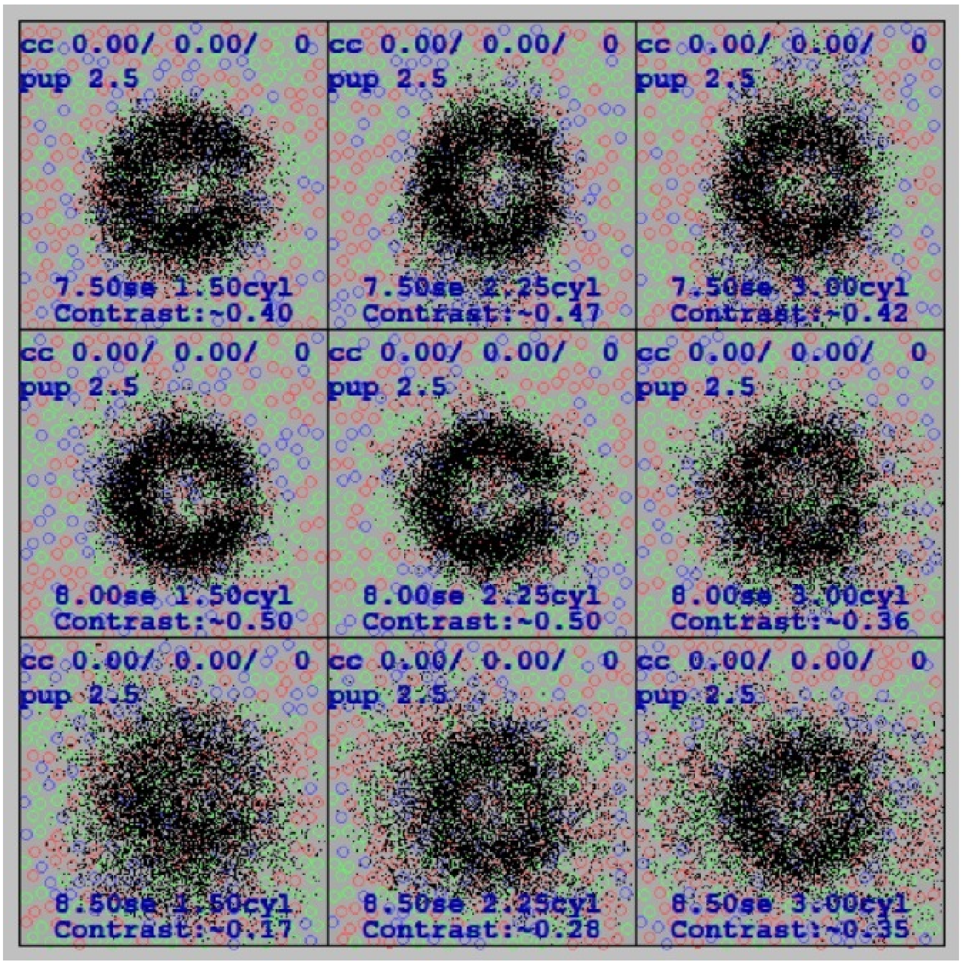


Figure 3.2: **Toric IOL**

This window is shown in addition in case of selection of a toric IOL out of the 4 IOLs in fig.3.1. The picture shows the visual impression of the numerically best fitting IOL power level in center, surrounded by the astigmatic and spheric neighbors. Other than in fig.3.1 no sphero-cylindrical correction is applied.

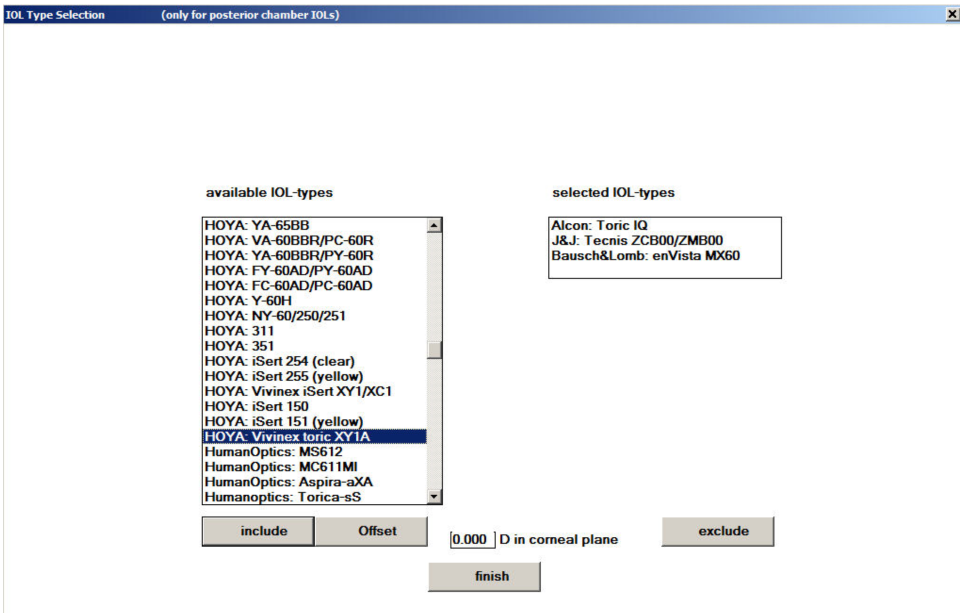


Figure 3.3: **Selection of IOL Types**

The right field shows the IOL already selected, the left one is a list of all available types. In maximum, four IOL can be selected. Each IOL in the right list can be removed by exclude*, each one in the left can be added by* include *as long as space is available in the right list.*
After clicking to the Offset *button an offset can be entered for the IOL highlighted on the left. This is logically equivalent to the "constant adjustment" with IOL formula calculations. Normally it is not recommended to enter such an offset* $\neq 0$.
Only IOL for capsular bag implantation can be preselected with this menue. Other IOL (anterior chamber IOL, add-on IOL) are available under OKULIX details, *button* 1IOL.

3.1.1 Tomey-TMS4

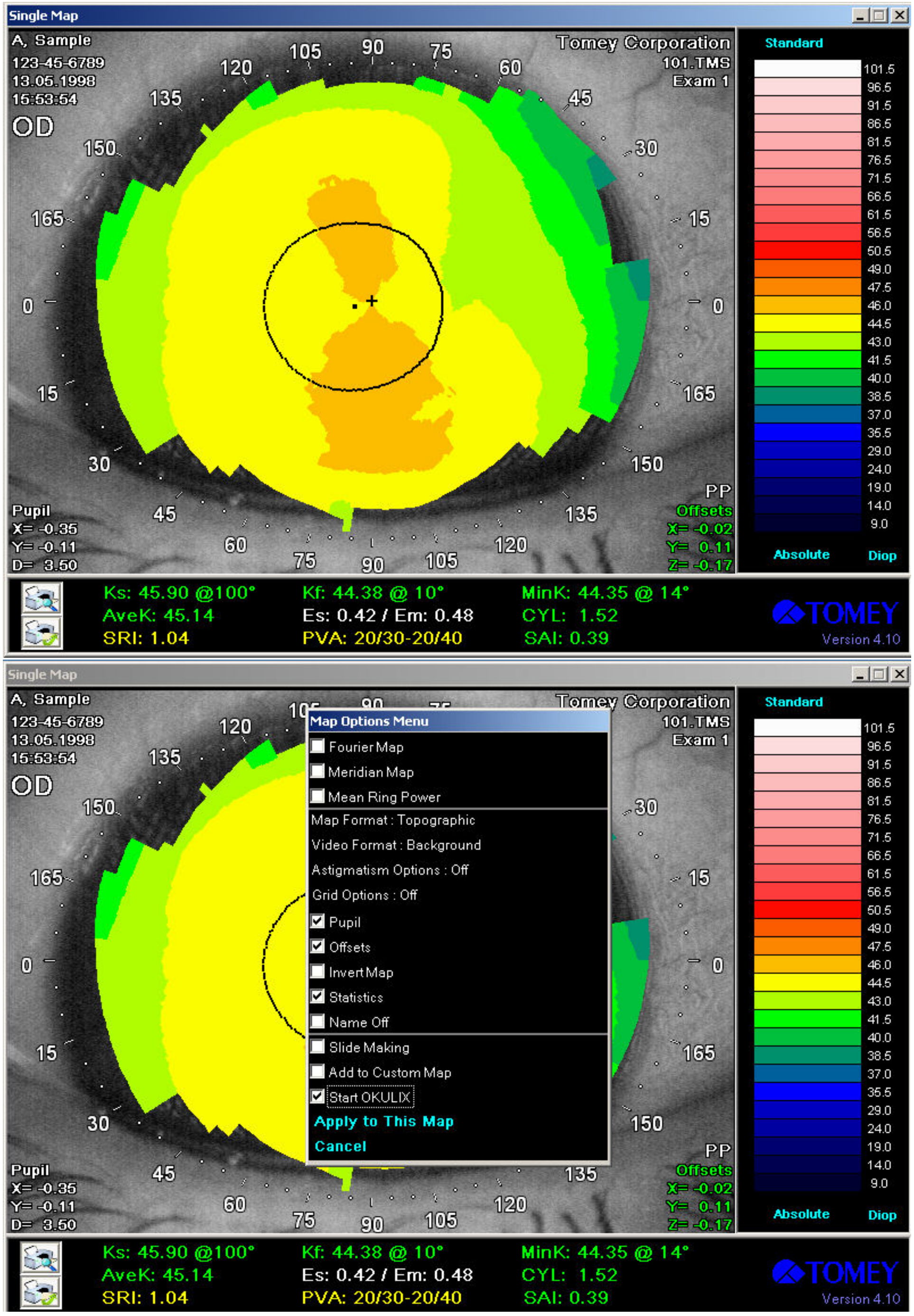


Figure 3.4: **Calling OKULIX from TMS**

After creating a TMS single map, set cursor into the image area and click right mouse button (upper image). Then activate the "Start OKULIX" field and click to "Apply to This Map".

3.1.2 Tomey-TMS4/TMS5 and Tomey-OA1000

Installation, IOL type selection OKULIX-call and workflow are principally the same as with the TMS4, see previous section, only from different windows inside the TMS-software. With the TMS5 the posterior corneal surface is calculated from the spatially resolved pachymetry data. Axial eye lengths data measured by OA1000 are automatically included in the data sent to OKULIX and used for IOL-calculation. Data recorded by the Tomey CASIA OCT can be used the same way.

3.1.3 Oculus Pentacam

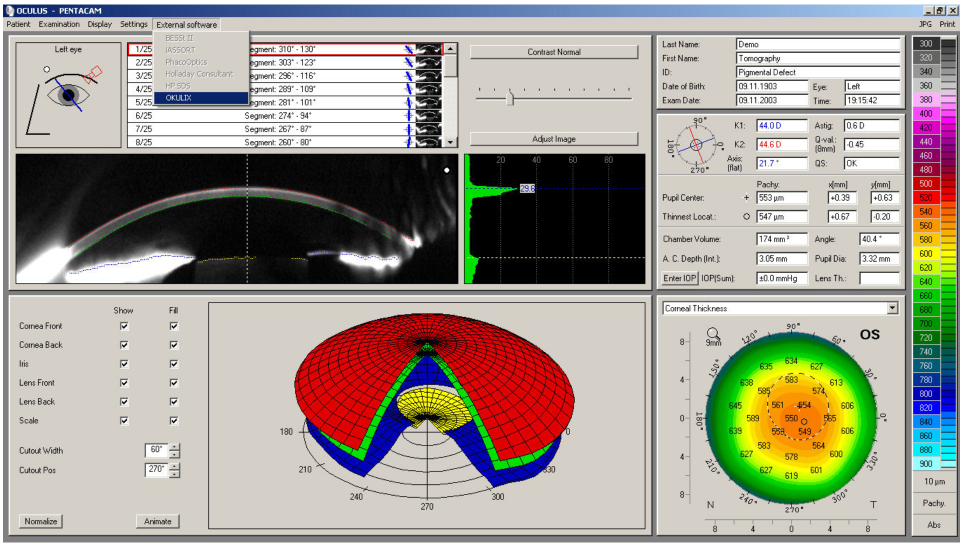


Figure 3.5: **OKULIX call from Pentacam**

3.1.4 Tracey iTrace

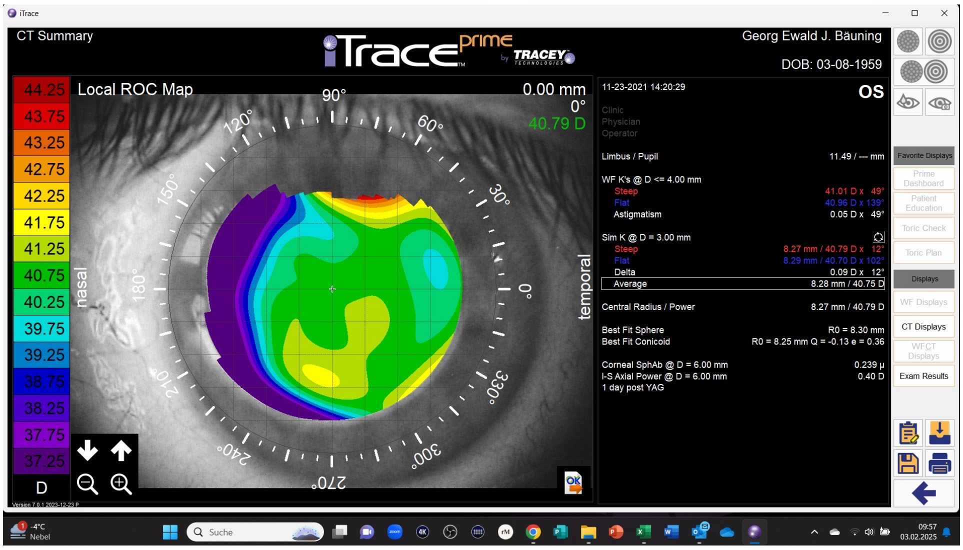


Figure 3.6: OKULIX call from the iTrace

3.1.5 Haag-Streit-Lenstar

The call of OKULIX is shown in fig.3.7. In this device, keratometry and axial eye length data are simulataneously transferred for both eyes, and the calculation in OKULIX is performed for both eyes immediately one after another. The position and thickness of the crystalline lens are used for an improvement of IOL position prediction.

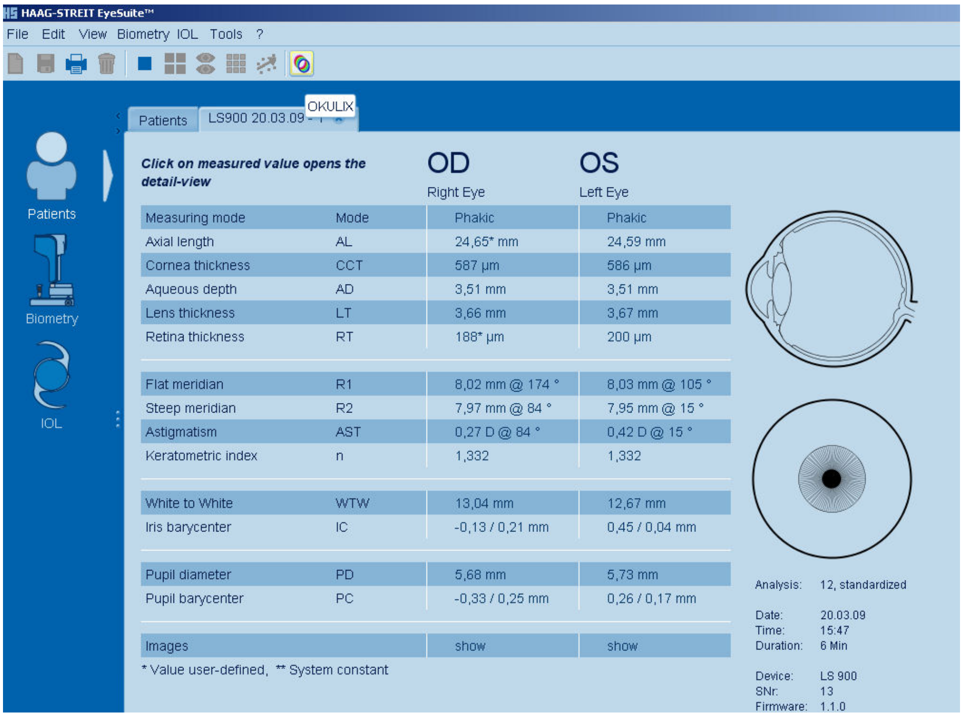


Figure 3.7: **OKULIX call from the Lenstar**

3.1.6 Combined Workstation Topography and Haag-Streit-Lenstar

One of the topography (or tomography) devices described in the previous sections can be installed in a workstation on the same computer with the Haag-Streit Lenstar. OKULIX then combines the data of both devices for subsequent calculations.

In this combination of devices the topographic data of both eyes *first* must be transferred to OKULIX. To do so, OKULIX has to be called twice, i.e. for each eye, as described in the previous sections. But OKULIX only confirms the successful data transfer without further calculations on call from the topography software, see fig.3.8. The IOL calculation is then performed when OKULIX is finally called from the Lenstar. Calculations initiated by the Lenstar without prior topography for one or both eyes are possible as well, in this case only based on Lenstar-keratometry.

In order to allow also a calculation for a single eye without Lenstar data, first a question appears if the topo data shall be used alone, see fig.3.9.

When topography *and* keratometry are measured, the user can select which of these data shall be used for corneal radii in IOL calculation, or if the average of both shall be used (default). Note:

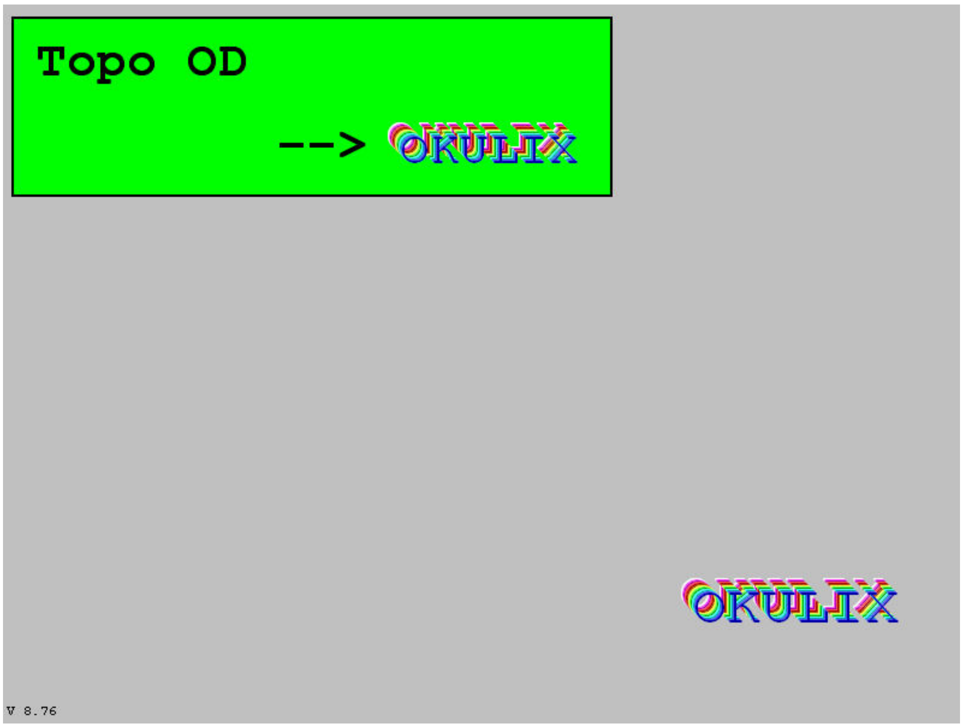


Figure 3.8: **Parameter Capture**

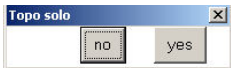


Figure 3.9: **Only topography, i.e. without Lenstar measurement?**

- Only topography contains the information on asphericity, and only additional pachymetry allows a correct calculation of posterior corneal surface. Both informations are particularly indispensable in eyes after corneal surgery. Therefore, in these eyes only topography should be used, not keratometry.
- Keratometry is less sensitive against tear film instabilities. In dry eyes it is therefore often more accurate than topography.
- In the majority of normal eyes it can be assumed that the mean of topographically and keratometrically measured radii is more accurate than each single of both.

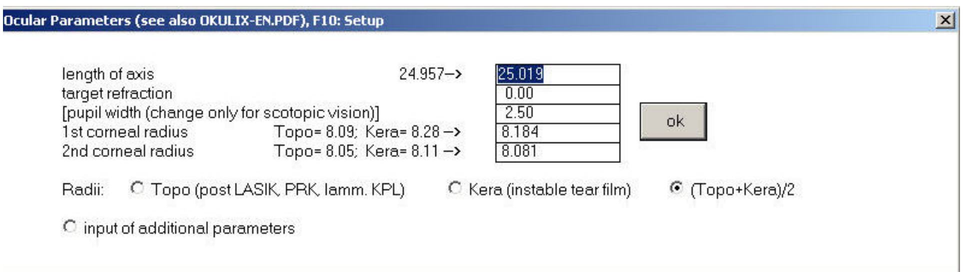


Figure 3.10: **Selection Keratometry / Topography**

Asphericities and posterior corneal radii are always extracted from the corresponding data sets when topography and pachymetry are measured.

3.1.7 Ziemer Galilei G6

The call from this device is shown in fig.3.11.

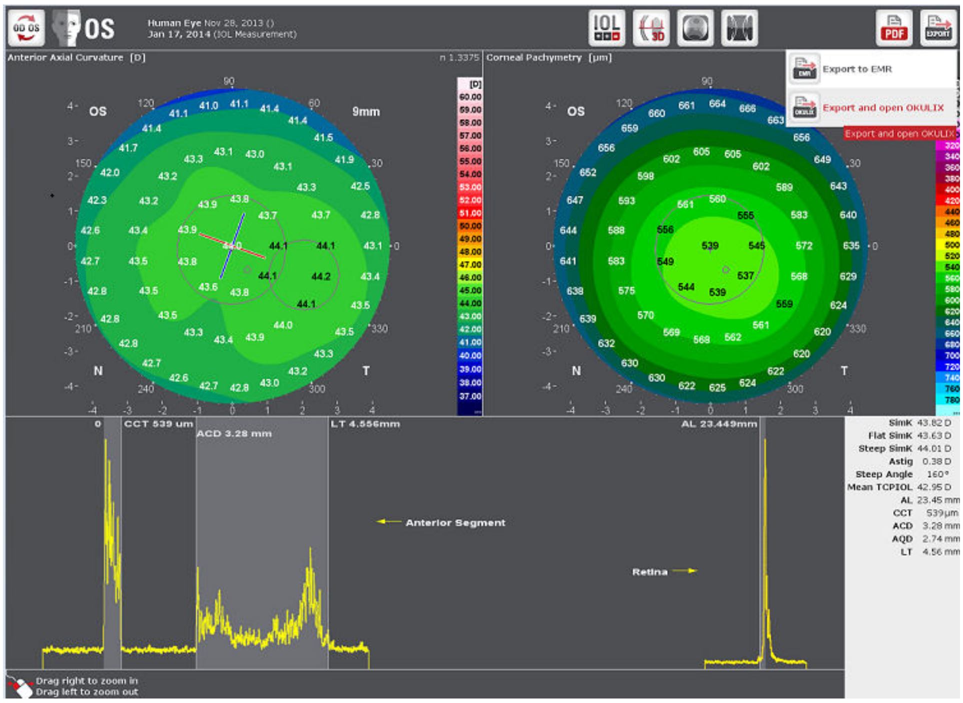


Figure 3.11: **OKULIX call from Galilei G6**

3.1.8 Heidelberg Engineering Anterion

The call from this device is shown in fig.3.12.

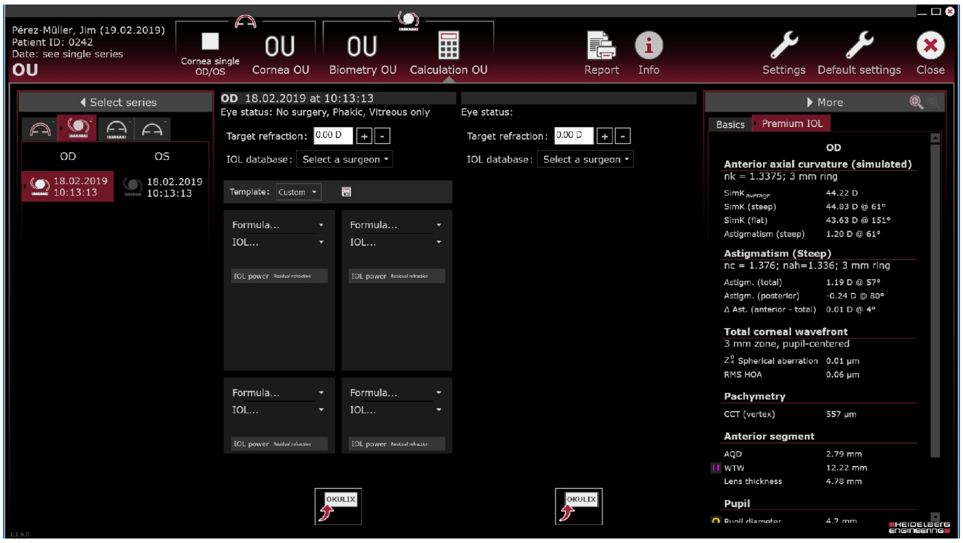


Figure 3.12: **OKULIX call from ANTERION**

3.2 PC Standalone Version

In the first window of OKULIX display resolution (640×480, 800×600, 1024×768, 1280×960 or 1600×1200) and language (Deutsch or English) can be chosen by clicking to the indicated fields, see fig.3.13. It is suggested to switch to the highest possible resolution for best image quality (however, longest calculation time). In difference to other Windows based programs, window size and location cannot be modified during program run.

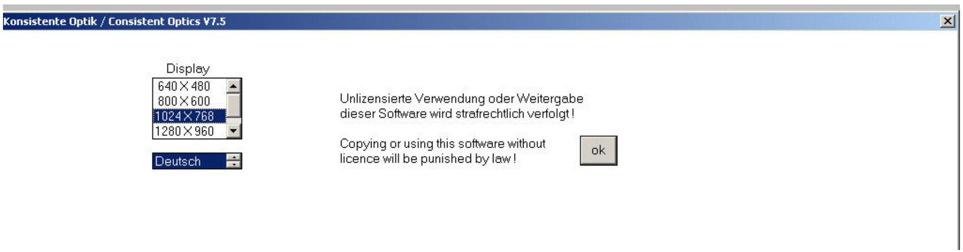


Figure 3.13: **OKULIX Starting Window**
Screen resolution and language (Deutsch or English) can be selected in this window.

Out of the different alternatives of the second window (fig.3.14) mostly the simultaneous calculation of up to 4 IOL will be selected. If these IOL types are not yet preselected, this has to be done as shown in fig.3.3. Special IOL models (phakic or add-on) cannot be selected here. They are available under 1IOL. The next steps for the simultaneous calculation of up to 4 IOL

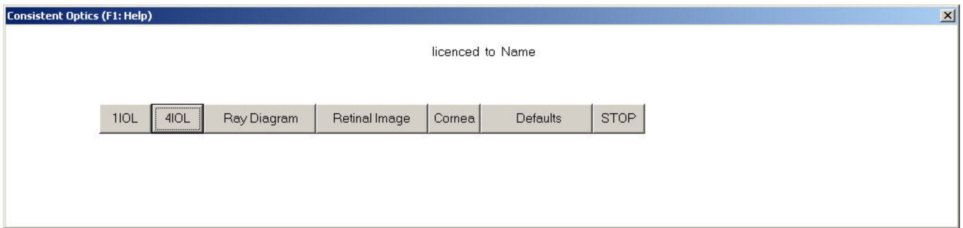


Figure 3.14: **Alternative OKULIX Branches**

are shown in fig.3.15, the result in fig.3.1 of the previous section.

Instead of left mouse button, also tab- or cursor keys together with the enter- or return key can be used.

If there are more than one printers installed in the computer, printouts are normally directed to the "default printer", however, the option "printer selecable" may be activated as well.

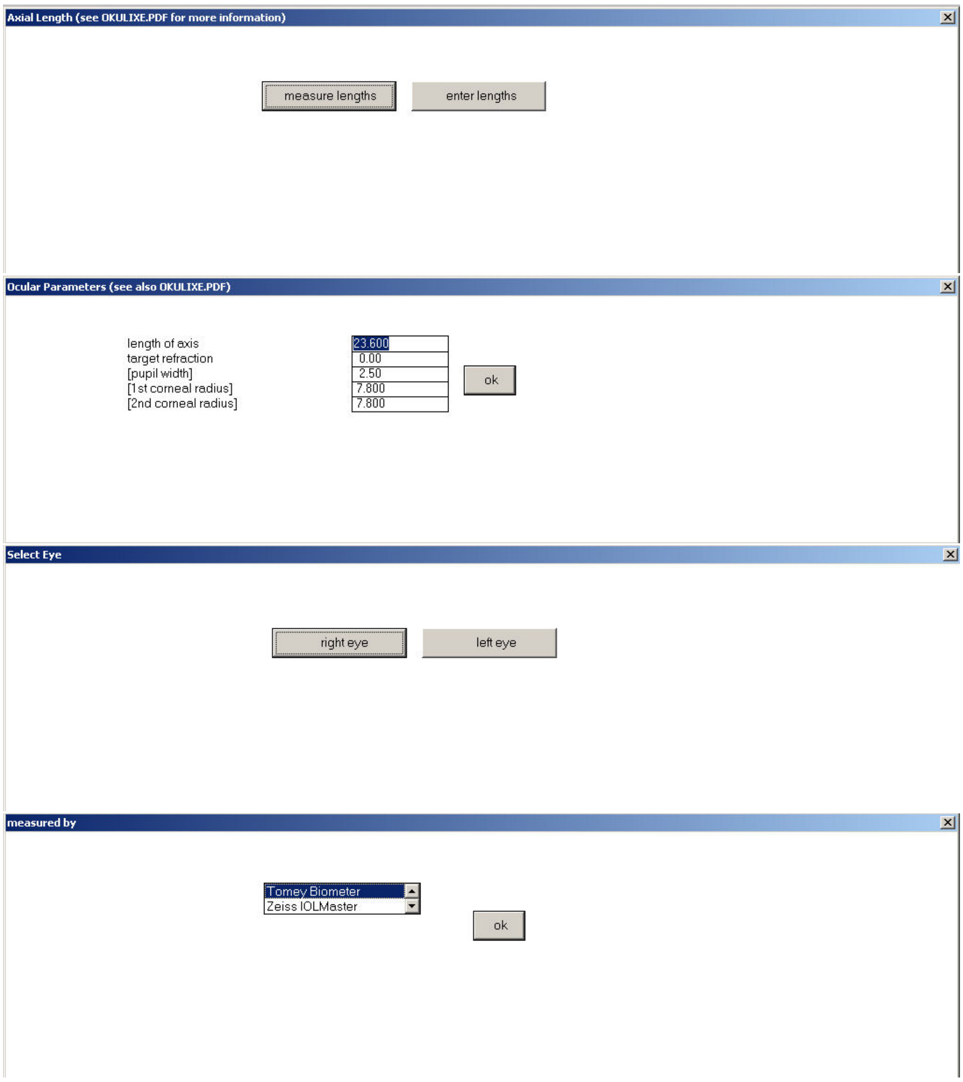


Figure 3.15: **The Next Steps**

3.2.1 Axial Eye Length Measurement with Tomey Biometer

Axial eye lengths data can be directly transferred if the measuring device is connected by a serial communication line. In this case also the transformation of length data is performed automatically. In order to avoid confusion of the eyes (right/left) the following order is to be observed:

1. measurement of the axial length of *one* eye
2. measure length in OKULIX
3. selection of the biometry device, after that, OKULIX is expecting the data
4. releasing of the data transfer in the biometer (see corresponding user manual)
5. selection of the eye (right or left) in OKULIX

After IOL calculation (and optional printout) the axial length of the second eye is to be measured. Because of the higher probability of operating errors the eye selection (right/left) preset in the biometer is not used in OKULIX.

3.3 Special IOL (toric, phakic, iris fixated)

Calculations of toric IOL, phakic IOL or IOL in an unusual position (e.g. sulcus fixation) or orientation (e.g. revers retropupillar iris fixated IOL) are possible in the branch 1IOL. Just the selection of the corresponding IOL model determines the subsequent steps, see fig.3.16, 3.17 and 3.18.

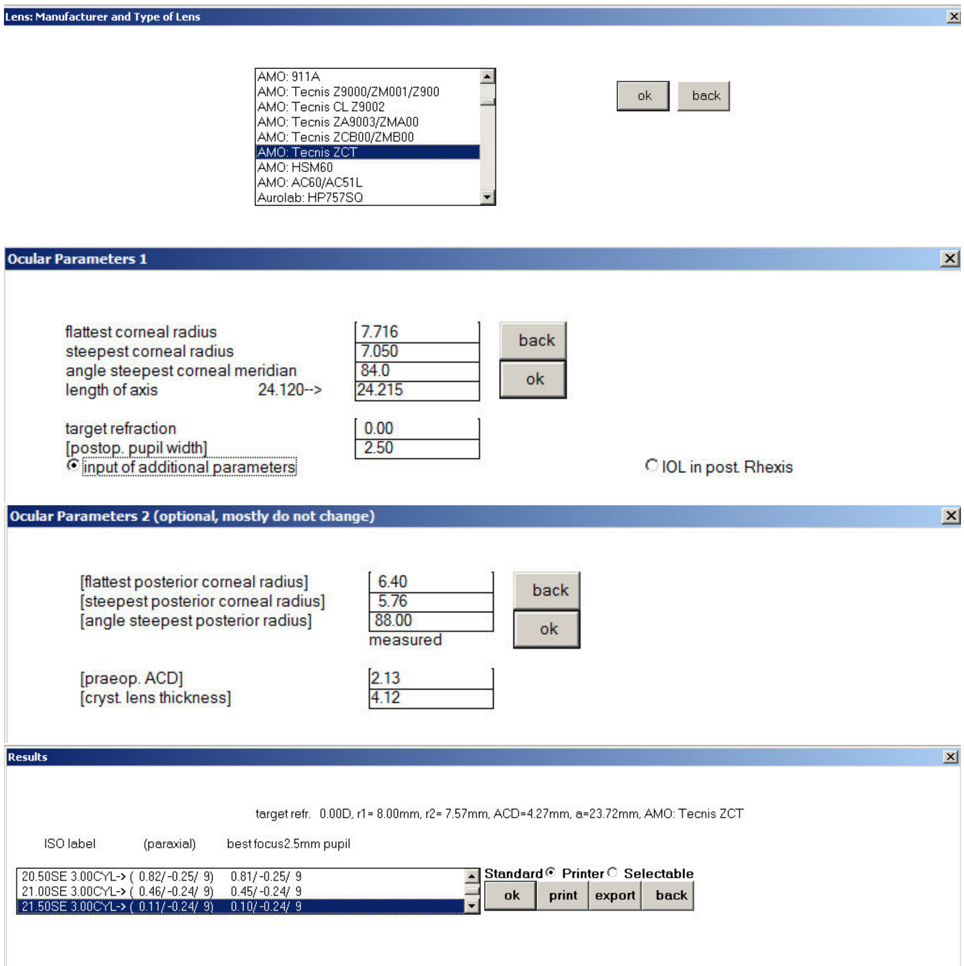


Figure 3.16: **Toric IOL**

The selection of the IOL model (1st Window) determines already the calculation of a toric posterior chamber IOL. The corresponing measured data can be either taken from directly connected measuring devices or manually entered or modified in the 2nd window.

Normally, the proposed values for the mean posterior corneal radius and for the most probable postoperative anterior chamber depth should not be changed, however, in special cases they can be modified in the 3rd window.

The 4th window shows the results, including paraxial refractions and best focus refractions depending on pupil width. IOL powers are given in the new ISO format with spherical equivalent (SE) and absolute cylinder power. For IOL implantation the mark on the IOL characterizing the IOL meridian of lowest refractive power has to be aligned with the corneal meridian of highest refractive power shown in red which can deviate from the angle of the steepest anterior corneal radius if the angles of steepest anterior and posterior meridians do not coincide. The total corneal astigmatism and the optimum implantation angle are printed out in red.

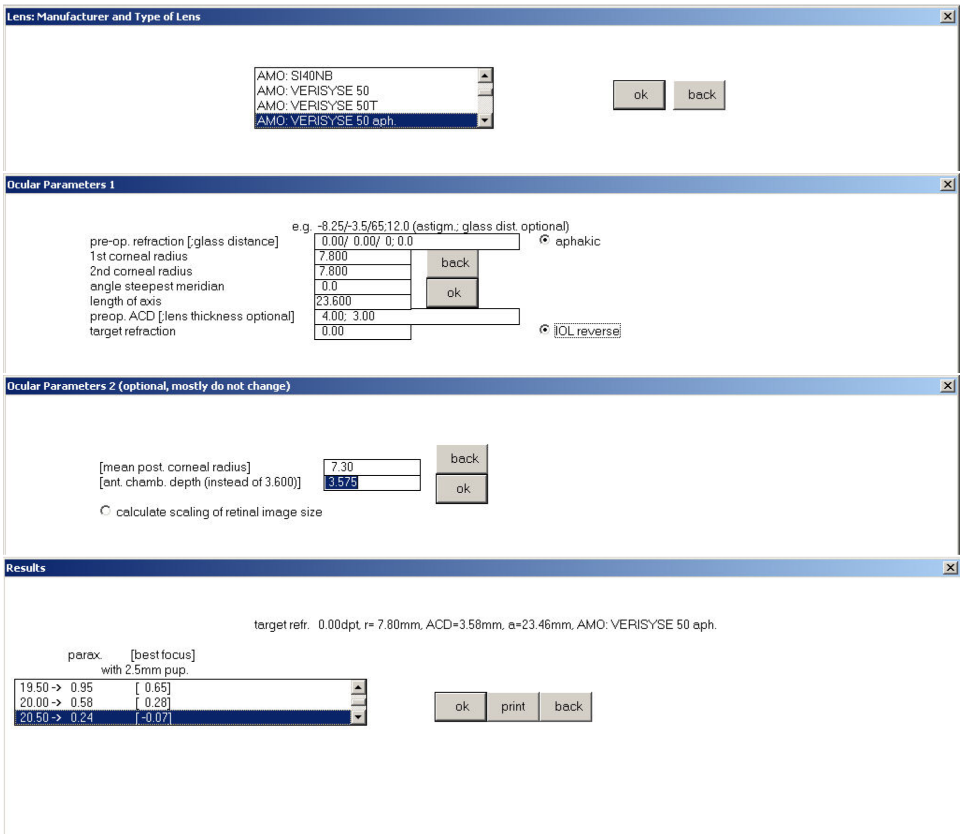


Figure 3.17: **Retropupillary Iris-Fixed IOL**

The IOL model selected in the 1st Window can be implanted either into the anterior or posterior chamber and fixed to the iris in both cases. It can theoretically also be used as a phakic IOL.

First, the 2nd window keeps all of these possibilities open. The retropupillary irisfixation is defined by the selection of the two options aphakic *and* IOL revers*. The input values normally needed for phakic IOL are not used, but only corneal radii, axial eye length and pupil width.*

The most probable postoperative ACD proposed in the 3rd window is much smaller than that for an IOL to be implanted into the capsular bag. If the irisposition can be measured, the proposed value should be modified correspondingly.

The 4th window shows the results, with paraxial refraction and best focus refraction for the given pupil width.

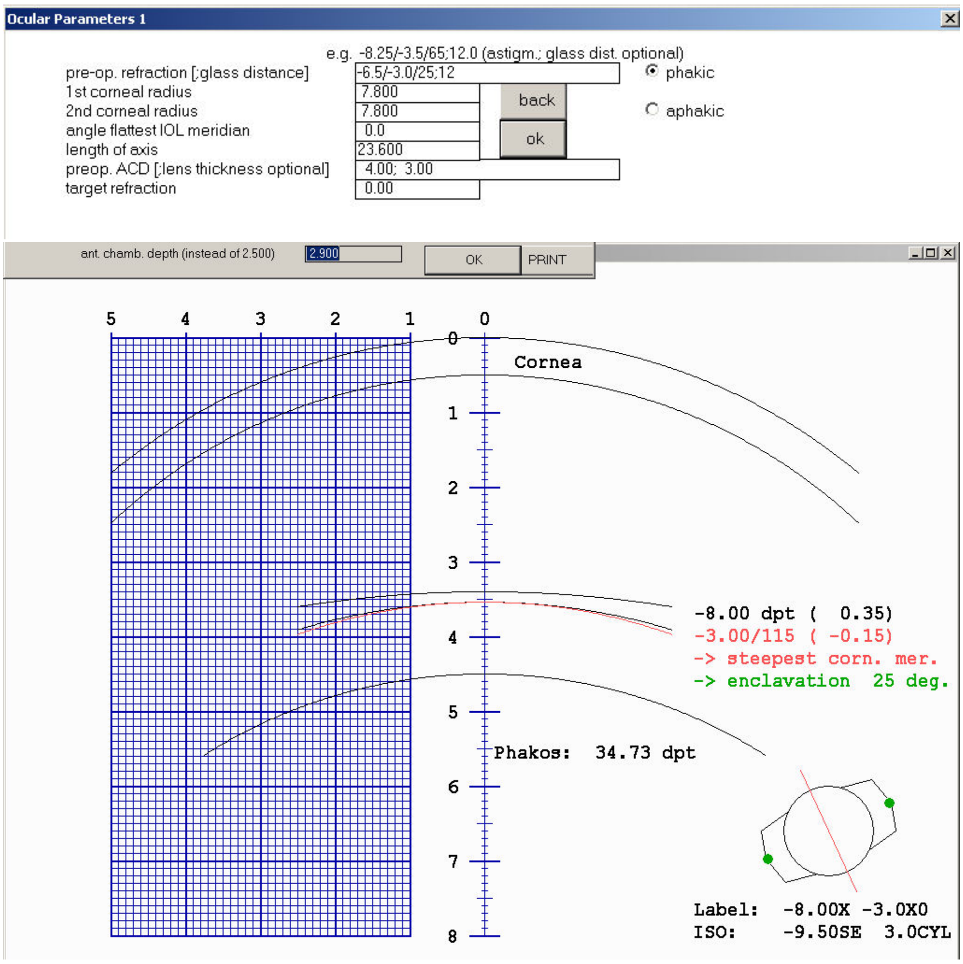


Figure 3.18: **Phakic, toric IOL**

Above: input window, below: drawing (which can be interactively modified) of the result. Corneal radii and manifest refraction do not neccessarily result in the same IOL. Therefore, the user has to decide which of these two informations calculation is to be based on. In the example shown here the phakic IOL is calculated for the refraction -6.5/-3.0/25°, corneal vertex distance 12mm. In refraction based calculations, corneal radii have only little impact on the resulting IOL power. IOL power, however, depends on the interactively variable IOL position (ACD=2.9mm in this example). The IOL model and orientation of implantation are shown in the lower right. The windows above automatically appear after selection of the corresponding IOL model.

3.4 Add-on IOL with Silicon Oil Endotamponade

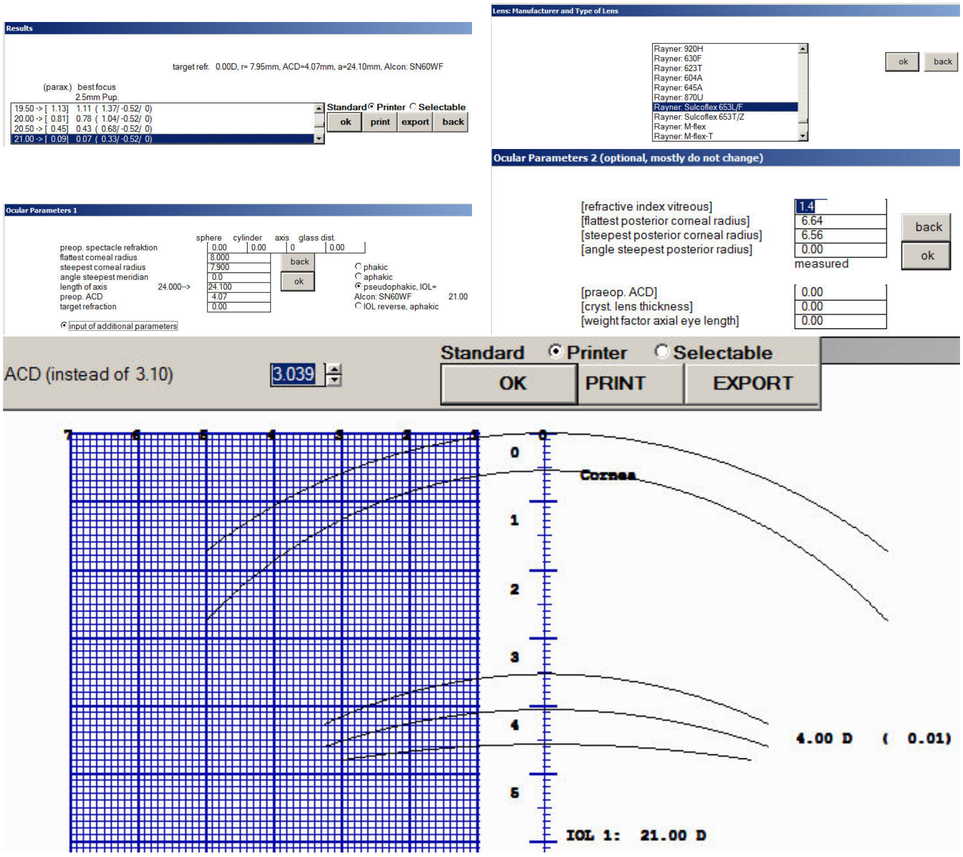


Figure 3.19: **Add-on IOL with Silicon Endotamponade**
At the beginning the IOL for capsular bag implantation is to be calculated which remains after oil removement (Alcon: SN60WF 21.0dpt). This must be done in the 1IOL *branch, not in* 4IOL*.*
Then, in 1IOL *the add-on IOL is to be selected which shall be implated into the sulcus to compensate the refraction error caused by the silicon oil (Rayner: Sulcoflex 653L/F).*
In the next window the previously selected posterior chamber IOL is shown under the already selected option pseudophakic, IOL=*. Now, the option* input of additional parameters *is to be activated. All other option are ignored.*
In the next window the refractive index of the vitreous must be set to the value of the used silicon oil (1.4).
Finally the window with the sulcus IOL to be implanted (4.0D) anteriorly to the IOL in the capsular bag (21.0D) opens. The refraction at the assumed ACD of 3.039mm is 0.01D.

3.5 Additional Examples

Some examples are given to make the use of the program easier for beginners. The description is more elaborated in the first examples and becomes shorter later in the text. All program buttons are written in sans serife.

3.5.1 Spherical Aberration

Start the program and adjust the screen resolution in the first window to full resolution (e.g. 1024×768), then: ok. This is neccessary only the first time the program is used. After that click to Retinal Image. The right and left subimage shows the same Landolt's ring superimposed to the retinal receptor grid. Instead of a Landolt's ring also the so-called "point-spread-function" can be displayed by activating the corresponding button. In this case the size of the retinal field is used instead of the visual acuity. The size of the Landolt's ring corresponds to visual acuity of 1.0 (20/20, "Vis" in the upper part of the image), pupil width ("Pup") is 2.5mm. Even if the starting parameters describe a paraxially exactly emmetropic eye that corresponds to a Gullstrand's eye (beside pseudophakia) the image is not really sharp. The blurring is caused by spherical aberration. It is responsible for the difference of paraxial emmetropia and best focus even for a pupil width of only 2.5mm. This difference can be compensated by a prescription glass. After clicking to Image Param. (upper left) a window opens in which such prescrition glasses can be defined. For the sphere now a value of -0.25[1] has to be entered, then: ok. The left image is shifted to the right, and on the left a new Landolt's ring is generated with the spherical ("Sph") prescription glass of -0.25 (red underlined). The image is significantly clearer.

3.5.2 Influence of Pupil Width

First remove the spherical prescription glass (enter 0.0 for the sphere). If now pupil width is set to 4.0 in the window that opens after clicking to Image Param., the resulting Landolt's ring shows a large halo. Such halos are reported from pseudophakic patients under mesopic conditions. The halo can be modified by minus-prescription glasses, however, visual impression never becomes satisfying. The variation range of the spherical aberration is so high, that always large areas contribute to the blurred part of the image information.

If now pupil width is stepwise decreased in the range of 2.5mm to 0.5mm with a stepwidth of 0.5mm, visual impression first is improved, but then worsenes again below 1.0mm. This is caused by the *diffraction* at the pupil aperture. The diffraction alone is responsible for a blurring inversely proportional to the pupil diameter. After all, reset pupil width to 2.5 before calculating the next example.

3.5.3 Subjective Refraction

For the examples presented so far an ideal spherical cornea with radius 7.8mm has been assumed. The data of a real cornea as measured by corneal

[1] All values have to be entered *without* unit (e.g. D or mm), otherwise an error message is produced. Therefore, the units are also omitted in the text of the examples.

topography are stored in the file DEMO.DAT which is automatically copied into the OKULIX directory during installation. In order to load this file, first click to Cornea, either from the starting menue or from the Retinal Image. If the installed OKULIX version also contains the corneal module (additional examples see below), the buttons of this module now appear. In this case click to Cornea Files. In the following window the different corneal files are displayed, so far containing just the DEMO-file. In case of an OKULIX installation without corneal module this window opens immediately after Cornea. If clicking to ok now, the file is displayed. The curvature radius is given as a function of location. The extracted mean central radius (7.972mm) and the central radii in the flattest and steepest meridian and the corresponding angles (8.06mm/12° and 7.88mm/102°) as well as the numerical eccentricity $e = 0.450$ are extracted from the raw data as described in [13].

If clicking to ok again the displayed topography is chosen for further calculations. If the corneal module is installed, click to STOP to exit from the corneal module.

As long as a corneal topography file is used for the calculations (i.e., corneal shape is not only defined by its global parameters), this mode is indicated by "cornea active" in a blue field at the uper right corner of the Retinal Image.

The Landolt's ring is now highly blurred. Following the rules of subjective refraction for a non-accommodating eye the best spherical glass of +0.5 is found by variation of the sphere. Keeping constant the sperical equivalent of +0.5 and applying sphero-cylindrical glasses in the sense of a cross-cylinder, the cylinder axis and power can be adjusted. Clearly, the minus cylinder axis must coincide with the axis of the flattest meridian. The best visual impression is achieved for (+1.25/-1.0/12°). This glass can also simply be obtained by activating the option best correcting glass.

3.5.4 Chromatic Aberration

All OKULIX-calculations are normally performed monochromatically at 540nm. The influence of chromatic aberration on subjectiv visual impression can be simulated by selection of a white spectrum (sun or bulb). The effect is relatively small. Therefore, the Landolt's ring should be already as sharp as possible. This can be achieved e.g. by the procedure as described in the previous subsection. In addition the contrast may be calculated for better objectivation. In reality, visual impression also depends on the spectral sensitivity of the retina which is different for scotopic and photopic conditions. As an alternative, also the spectral sensitivity of a commercial CCD-camera can be selected being more sensitive in the red. Selection of additional glasses in the order of 0.1 diopters helps to demonstrate the defocuss caused by chromatic aberration.

3.5.5 Corneal Module

This module is relevant for corneal refractive surgery. For IOL power selection only (including adaption after corneal refractive surgery) it is not necessarily required. The corneal module is called either from the main menue or from the Retinal Image by clicking to Cornea.

3.5.5.1 2-Dimensional Optical Errors

Choose the DEMO topography by clicking to Cornea Files, then select (ok) and load (ok once again) it. Then click to 2-Dim. Opt. Error. Refraction errors are calculated in two dimensions: meridional, i.e. in the direction of the meridians, and azimuthal, i.e. perpendicular to the first. The vector sum of both components is the total refraction error which is calculated e.g. for the blurring of the Landolt's rings. The azimuthal component mainly describes the deviation from the rotational symmetry. Other than the meridional component, the azimuthal one is not influenced if spherical power is changed. In addition, optical path length differences to the center (so-called "wavefrontdifferences") are calculated by clicking to Wavefront Diff.

These three optical errors (meridional, azimuthal or wavefront differences) can be displayed either exactly, i.e. the results of the ray-tracing, or these data can be approximated by a Zernike polynomial series. To do so, first the corresponding option has to be highlighted. Than the maximum radial order [3-12] of the series has to be entered. If 0 or nothing is entered, the exact error map is displayed. If a Zernike series has been calculated, the coefficients can be stored in ASCII-format on a file for which the name has to be entered additionally. No such file is generated if no name is entered. In adition, the Zernike coefficients are displayed in a window and can be manually changed.

We start with meridional. In the following branch for the pseudocolor mode it is proposed first to click to automatic. This means that pseudocolors are adapted in such a way that "in mean" a useful dynamic range is covered. This, however, is normally not exactly the range the user is willing to see. The procedure should be repeated therefore, this time clicking to user-defined for the pseudocolors. For the upper threshold +1.5 may be entered, for the lower one -3.0.

Below the map the RMS error (root mean square) is shown inside a circle of 3mm radius around the center.

Of course, the pseudocolor maps as well as the RMS-values strongly depend on the IOL. The circle, for which the RMS-values are calculated, has the radius of the optical zone of the IOL. This is also taken as the „unit circle" for the calculation of the Zernike series.

Clicking to azimuthal generates the pseudocolor map of the azimuthal refraction component. Their dynamical range is normally much smaller compared to the meridional one. Therefore, the pseudocolor range is always calculated automatically.

For Wavefront-Diff., the error map of the optical path length differences including the RMS error are shown.

If after Wavefront-Diff. 4 is entered as the maximum radial order of the Zernike approximation, the RMS-value is marginally changed. In addition, the image has a diameter of only 6mm in maximum (diameter of the IOL optics).

3.5.5.2 Corneal Model

In many applications, particularly in corneal refractive surgery, the use of an approximation of the corneal shape by only a few parameters is more advantageous than using the whole set of topographic raw data. This is what we call a *corneal model*. Such a model can be calculated from the topography by extracting these parameters. Alternatively, the parameters may simply be entered into OKULIX.

Choose the DEMO topography by clicking to Cornea Files, then select (ok) and load (ok once again) it. Then click to Corneal Model. For all following calculations R1,R2,alpha,e should be preferred, not Zernike-Approx.. The number of independent parameters is much smaller (four), the first three of them are commonly used in ophthalmology, and at least the central 4mm-zone is approximated with higher accuracy than by Zernike polynomial approximation [13].

If the radio button "reconstruct full zone" is activated by clicking on it, the missing data points of the topography are reconstructed.

Clicking to R1,R2,alpha,e opens a window in which corneal radii, angles and numerical eccentricity are preset with the same values as displayed in the topography. If other values are entered here, an arbitrary cornea can be generated in the computer. If clicking to ok, the values are applied.

After the calculation of the model approximation the values shown for radii and numerical eccentricity are slightly different from the starting values. The new parameters are extracted again from the two-dimensional data set. The said differences therefore demonstrate the accuracy of the approximation.

Also the deviation of the model approximation from the raw data can be quantified exactly. To demonstrate this, first the DEMO topography has to be loaded again. Choose the DEMO topography by clicking to Cornea Files, then select (ok) and load (ok once again) it. Then click to Diff. to Model. Now choose R1,R2,alpha,e. The result of the comparison is the difference between the original data and the model, displayed in pseudocolors. The difference can be alternatively given in height (mm) or refraction (D) units.

3.5.5.3 Lasik / PRK

Choose the DEMO topography by clicking to Cornea Files, then select (ok) and load (ok once again) it. Then click to Lasik/PRK. The paraxial ("old") refraction is shown.

We start with a myopic correction and therefore we enter -3.0 for the old refraction. All other parameters should remain unchanged for simplicity reasons, therefore: ok. The program now askes whether spherical aberration is to be minimised. This is the default procedure. The corneal asphericity is adapted to the IOL data resulting in a total spherical aberration close to zero. Select this default (ok). After that, the slightly oval ablation profile is displayed in pseudocolors. A little window opens in the upper left corner in which the name of the "shot-file" can be entered. If such a name is entered, a new window opens to select the laser type. In our example, nothing should be entered, i.e.: ok. After that we are asked if the ablation profile has to be ablated from the cornea (in the computer) or not. Click to ablate. The procedure can be performed exactly or with errors in order to demonstrate their influence on the result. We choose exactly. Now the topographic map is replaced by the corresponding map after laser ablation. Also corneal thickness is replaced by the modified two-dimensional profile (but not indicated).

The quality of the result can be checked in two different ways. First click to 2-Dim. Opt. Error, then meridional refr. and user-defined for the pseudocolors. Enter 0.2 for the upper and -0.2 for the lower threshold. The pseudocolor map shows that the major part of the optical zone is very close to 0.0.

If you exit from the corneal module by STOP and click to Retinal Image, you can generate a Landolt's ring which is recognizable also for a pupil width of 4.0 and a size corresponding to a visual acuity of 2.0 (20/10), provided the spherical prescription glass has been set to the target refraction (eagle's eye). To do so, click to Image param. and then enter the said values.

In the same sense an hyperopic correction can be simulated by entering e.g. +3.0 as the old refraction, starting from the same values as for the myopic correction.

Even if the results seem to be ideal, the ablation profile should not be calculated in the described manner. The laser ablation can never be executed with the same precision as the calculation. Therefore, high-frequency errors would not be corrected at their location in the topography, but always slightly shifted. This in fact amplifies the high-frequency errors at the current state of the laser technology. However, the problem can be solved if the measured topography is replaced by the "corneal model" (see previous section). This does not contain any high-frequency errors. Therefore, they are smoothed out.

Chapter 4

Legal rules

4.1 Licence agreement

The end user has the right to install and run OKULIX on one ore more computers belonging to his possession *and* property. Beyond that, he has no additional rights in the software. Sale or other transmission to third parties, as whole or in part, are not allowed in any case. Installation must be performed only from the OKULIX distribution medium. Copying this medium or copying the installed program is not allowed. Installation on computers, which belong to the property, but not to the possession of the end user, or vice versa (e.g., on borrowed or hired computers) is not allowed.

4.2 Warranty

OKULIX including the IOL data base has been provided with greatest care. Nevertheless, errors cannot be generally excluded. Also data errors on the distribution media are possible. Such errors can also occur later, even if the medium was free of errors at the distribution time. In addition, the IOL data from the IOL manufacturers may contain errors. Therefore, these data are checked automatically for plausibility and consistancy before beeing implemented into the OKULIX data base.

If errors in the OKULIX program are recognized, the manufacturer should be informed immediately. The customer will be supplied with a corrected software version on a new distribution medium as soon as possible. If an error occurs in the OKULIX program or in the IOL data base, the customer will be supplied with the new distribution medium free of costs. If the distribution medium was error-free at the time of distribution, but an error on the medium occurs later, the customer should send the distribution medium to the manufacturer. During the first two years after purchase, he will get a new medium free of costs. At a time later than two years after purchase, he has to pay the update basic fee.

4.3 Exemption from liability

The manufacturer bears **no liability for consequential damages** resulting from an application of OKULIX, particularly for damages from erraneous IOL calculation or corneal refractive surgery. The user of the program has to make sure himself by plausibility considerations that the proposed values do not contain gross mistakes.

4.4 Legal devolution

Possible customers of OKULIX, who do not agree to the rules stated above, have to return the OKULIX distribution medium to the distributor **before opening the seal and within one month after distribution**. The price will be refunded in this case. Opening the seal or keeping the distribution medium for more than one month admits the rules as stated above.

Chapter 5

Results in Patients

This chapter contains some typical results of OKULIX calculations in different patient collectives. They shall demonstrate which accuracy can be expected when using OKULIX.

Fig.5.1 and 5.2 shows results of two different hospitals for eyes without prior surgery. The mean results are very close to zero and not significantly different from each other. Fig.5.3 shows the importance of the allowed manufacturing tolerances for IOL. Further error contributions are the measuring errors of axial eye lenths and corneal radii and the estimation errors of the most probable IOL position.

In [22] for 10 eyes after corneal refractive surgery a prediction error with OKULIX of 0.31 ± 0.84D was found, however, these results are based on measurements of only the anterior corneal surface. Results using full corneal tomography are shown in fig.5.4.

Fig.5.5 and 5.6 show the reduction of astigmatism in 50 eyes by implantation of toric IOLs (Data P.C. Hoffmann, Castrop-Rauxel).

Fig.5.7 shows the difference in the achievable predicition errors depending on the final visual acuity and on the IOL asphericity [6].

In summary the results with OKULIX as a *physics based* method are in particular in eyes whith higher deviations from the average more accurate than the results of *statistics based* methods. As an example, in eyes after Lasik or SMILE the results of OKULIX had the highest accuracy amongst the competing methods [24, 9, 2]. However, a comparison between all currently relevant IOL calculation methods in 1442 eyes also showed highest accuracy for OKULIX in these “normal” eyes [1].

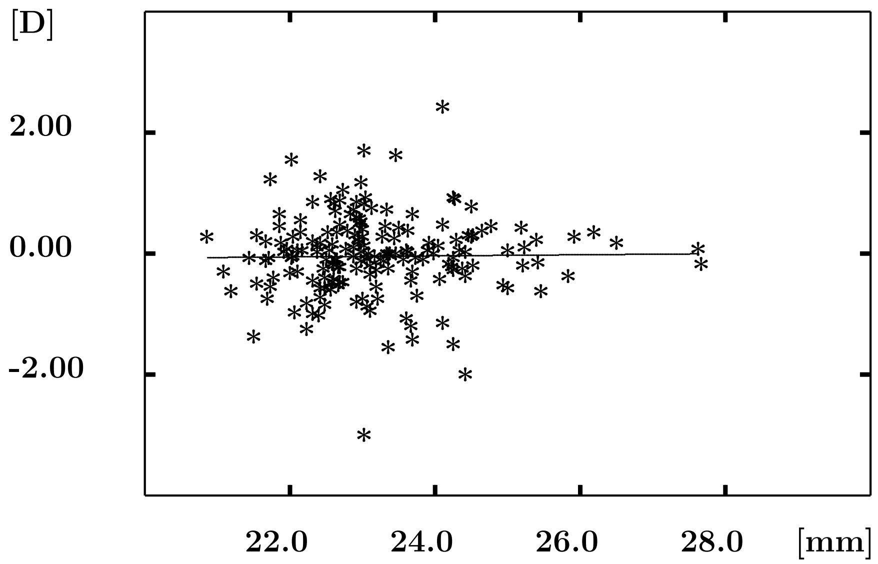


Figure 5.1: **Prediction Error of the Refraction**
This error [D] is the difference between the refraction calculated with OKULIX and the measured postoperative refraction. It is shown as function of the axial eye length [mm]. For a collective of 153 eyes the mean prediction error is -0.05±0.67D. The slope of the regression line (0.009D/mm) is not significantly different from zero. Alltogether, 7 IOL types have been implanted. (Data: O.Findl, Univ. Eye Hospital Vienna)

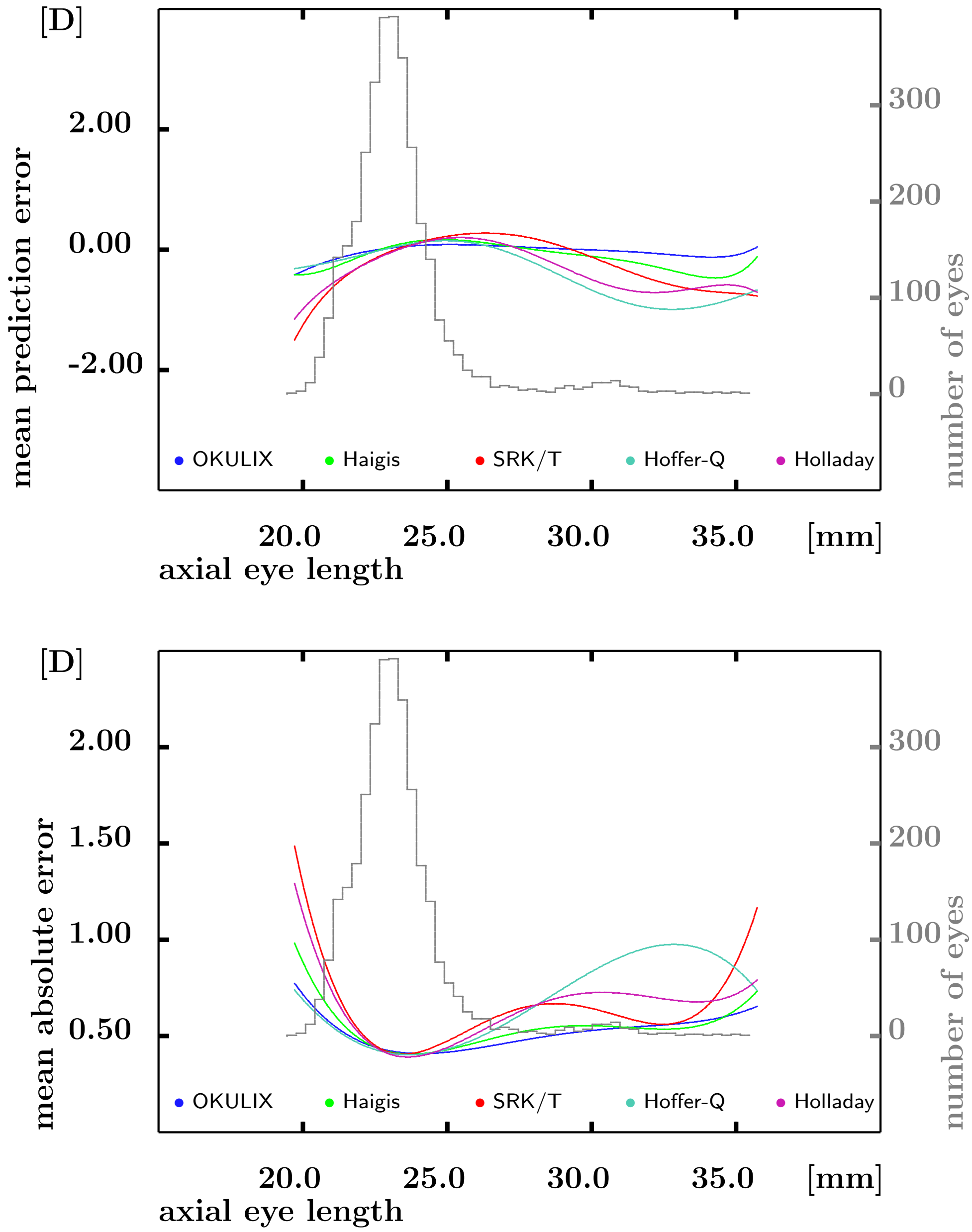


Figure 5.2: **Prediction error in comparison to formulae**
The results of OKULIX *are compared with frequently used formulae after adjsusting the so-called "formula constants" in 3246 eyes with altogether 9 IOL models. The data are fitted by eight order polynomials. Upper image: mean predicition error, lower image: mean absolute error. (Data: P.C. Hoffmann, Castrop-Rauxel)*

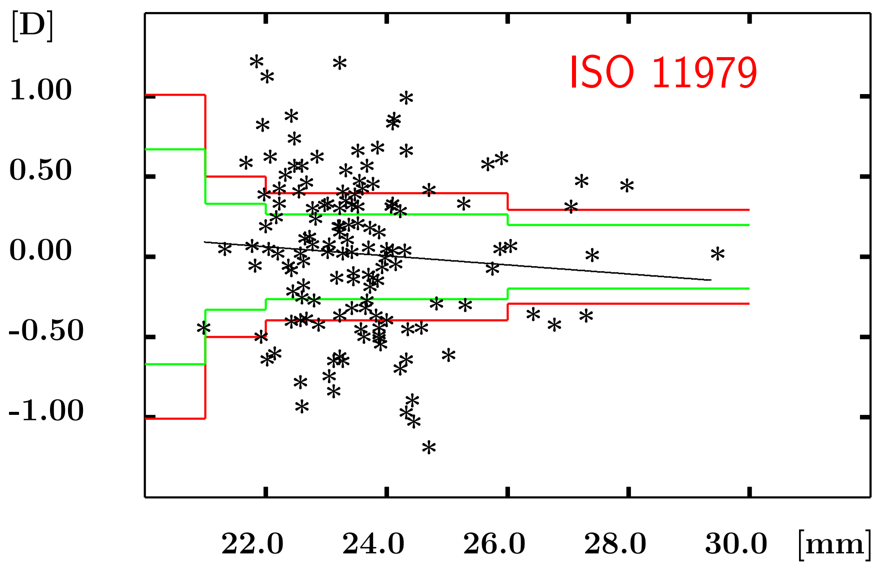


Figure 5.3: **Prediction Error and Manufacturing Tolerances**
The prediction error [D] of 136 eyes implanted with a AMO Ar40e, calculated with OKULIX, is shown as a function of axial eye length [mm]. The data are a subset of fig.5.2. The red lines indicate the absolute allowed tolerances for IOL manufacturing errors from the DIN/EN/ISO 11979, the green lines the corresponding values in corneal plane. The diagram contains two simplifications, which, however, do not change the message of this picture nor the order of the error amount:
1.) The DIN/EN/ISO 11979 refers to IOL powers rather than to axial eye lengths. The steps in the red and green lines therefore correspond to eyes for which corneal radius and ACD is set to the mean value with respect to the corresponding axial lengths.
2.) The ratio of refraction error in IOL plane to refraction error in corneal plane is also taken for mean values. (Data: P.C. Hoffmann, Castrop-Rauxel)

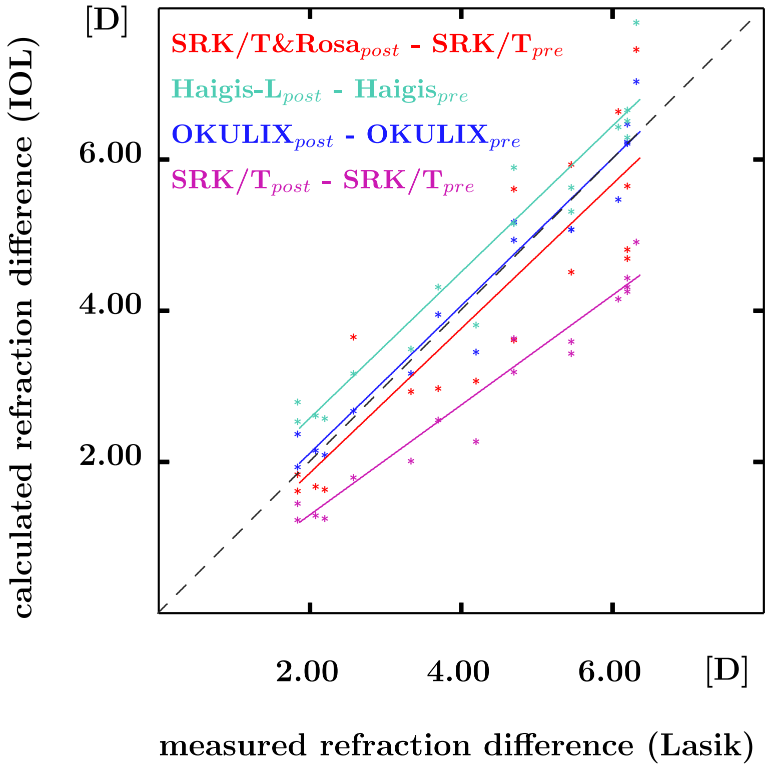


Figure 5.4: **IOL Calculation pre and post Lasik**
In 17 eyes corneal tomography with Tomey TMS-5, axial length measurements with Zeiss IOLMaster and, based an these data, IOL calculations were performed pre and post Lasik. The differences between these IOL calculations (spherical equivalent) are shown as function of the achieved Lasik correction. The results are independent on "formula constants" because the same values are used for pre and post Lasik. (Data: T. Hofmann, Vista-Clinic Binnigen, Schwitzerland).

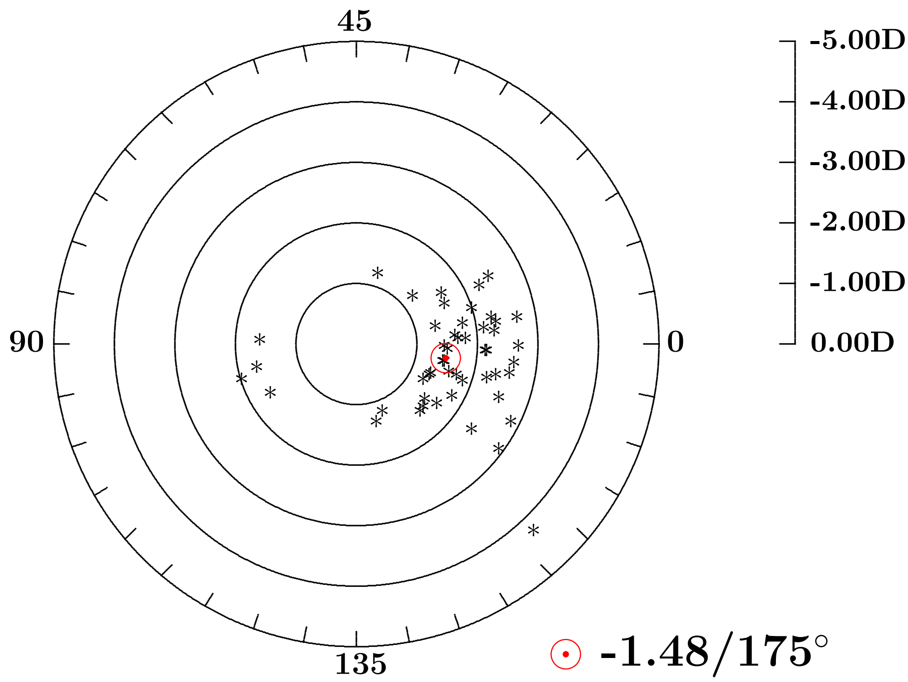


Figure 5.5: **Preoperative astigmatism**

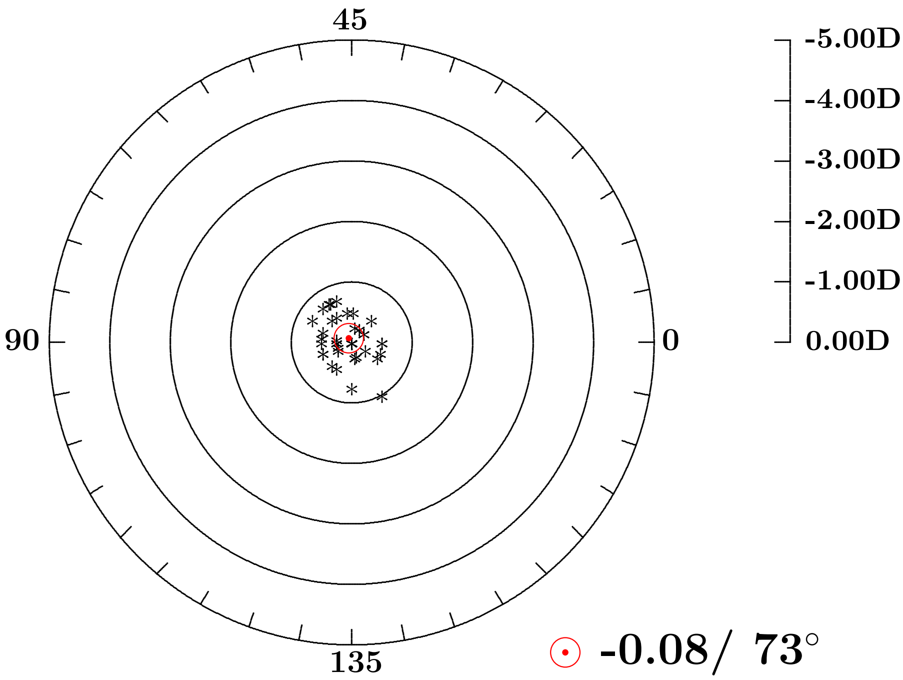
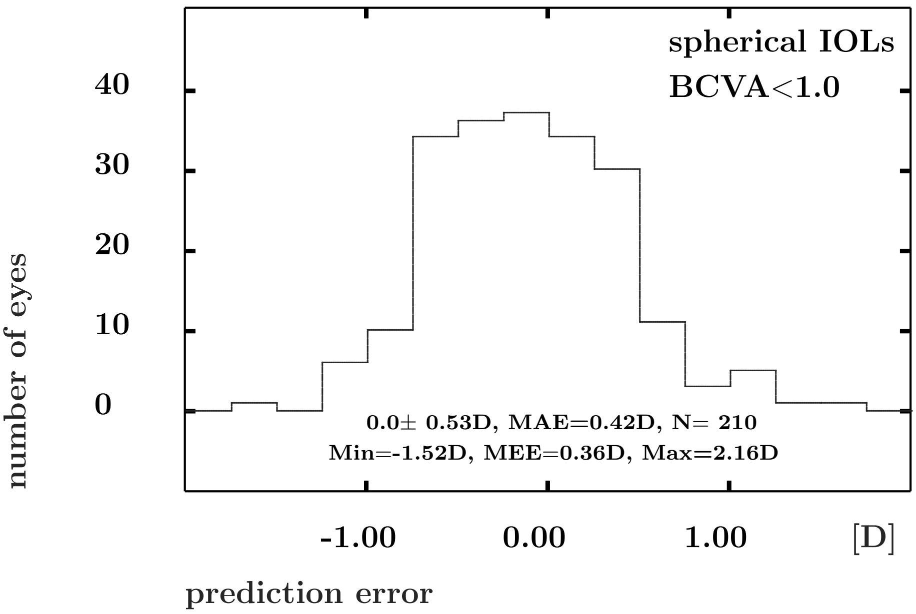


Figure 5.6: **Postoperative astigmatism**



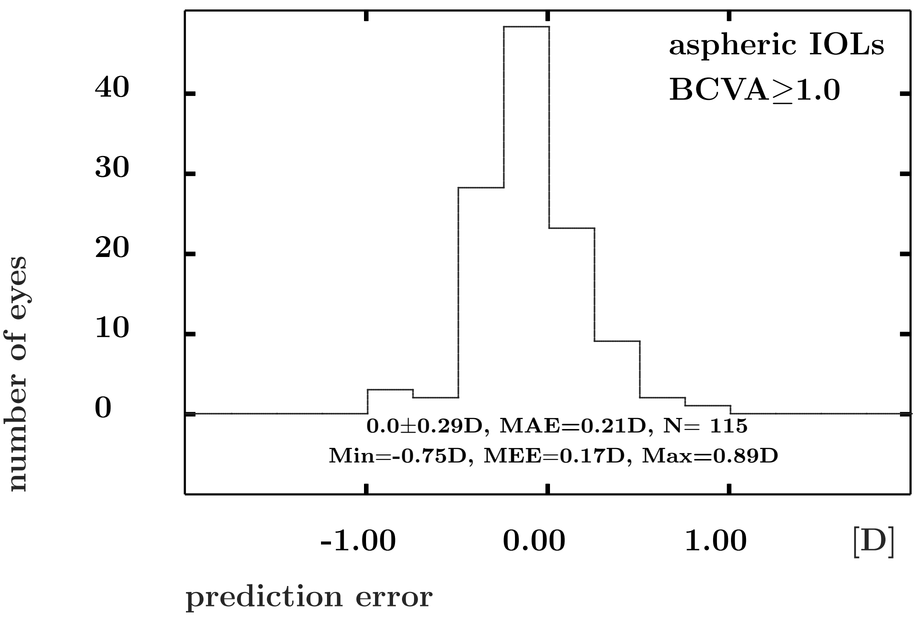


Figure 5.7: **Prediction Errors of 2 Subgroups**
The histogram plots of the distribution of the prediction errors are shown for the subgroups with the highest (top) and with the lowest (bottom) prediction errors. In the upper subgroup, 67% are within ±0.5D of the target refraction, 95% within ±1.0D, in the lower one, 91% are within ±0.5D and 100% within ±1.0D. (MAE: mean, MEE: median absolute error, both after offset correcetion)

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