41 The Haigis Formula

Wolfgang Haigis and Kenneth J. Hoffer

The Thin Lens Formula

Popular formulas for intraocular lens (IOL) power calculation like the Hoffer Q [1], the Holladay 1 [2], and the SRK/T [3] are based on the optics of thin lenses. In thin lens optics, cornea and lens (crystalline or IOL) are replaced by infinitely thin lenses (Fig. 41.1) with refractive powers K (corneal power) and P (IOL power), separated by a distance d. This fictional distance is sometimes referred to as optical anterior chamber depth (ACD, measured from epithelium to IOL principle plane), which has no measurable counterpart, in contrast to the acoustical or optical ACD measured by biometers (from epithelium to lens). In 1997, Holladay [4] proposed the term effective lens position (ELP) for d.

where D_L dioptric power of the lens (or IOL), L axial length (AL), R corneal radius of curvature, $n = 1.336$, $d =$ ACD, $R_X =$ refraction (desired or actual), d_x = vertex distance (=12 mm), D_C dioptric power of the cornea, and n_C index of refraction of the cornea.

Thus, all theoretical formulas may be reduced to the elementary thin lens formula:

$$D_L = \frac{n}{L-d} - \frac{n}{\frac{n}{z} - d} \text{ where } z = D_C + \frac{R_x}{1 - R_x \cdot d_x} \text{ and } D_C = \frac{n_C - 1}{R} \quad (41.1)$$

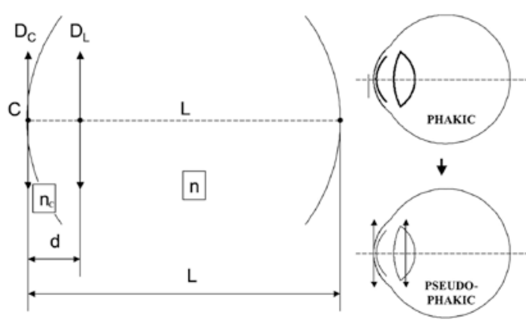

Fig. 41.1 Thin lens model: emmetropic eye where the cornea and lens are reduced to infinitely thin lenses

Wolfgang Haigis was deceased at the time of publication.

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The theoretical formulas differ in how measurement values from a patient are translated into the variables L, d, and D_C of Eq. 41.1. Table 41.1 gives an overview of how different formulas handle this conversion. Included is the calculation according to Haigis [5],[A,B] which is dealt with in more detail later. The individual recipes for data translation reflect of course the different working set-ups of the formula authors.

The main differences between the theoretical formulas lie in the prediction functions for the optical ACD or d, i.e., in the terms for d for each of their formulas. These functions depend, among others, on the AL; they are necessarily based on the author's experience with one or more IOL types in the form of individual constants like Hoffer's "personalized ACD" (pACD), Holladay's Surgeon Factor (SF), or the A constant (SRK/T). All of these constants may readily be transformed into each other [6, 7]. For example, if the A constant =118.0, then the SF = 1.223 and pACD = 4.97. Figure 41.2 shows such prediction curves (optical ACD d vs AL) for the Hoffer Q, Holladay 1, and SRK/T formulas, all based on an A constant of 118.0.

Since all IOL constants may be calculated from each other, there is basically just one constant, i.e., one number characterizing a given lens for all available powers, irrespective of IOL shape factor, lens material, index of refraction, diameter, etc. This, in the author's opinion, is insufficient for a meaningful lens characterization, as will be illustrated below.

Table 41.1 Differences in theoretical IOL formulas: all are based on thin lens optics (Eq. 41.1)

Formula	n_C	L	IOL constant
SRK/T	1.3330	AL + fx (AL)	A constant
Holladay 1	4/3	AL + 0.2	SF
Hoffer Q	1.3360	AL	pACD
Haigis	1.3315	AL	a_0, a_1, a_2

where n_C index of refraction of the cornea, *fx* function of, *SF* surgeon factor, *pACD* personalized ACD. AL in these formulas is the ultrasound measurement from the cornea epithelium to the anterior surface of the retina, whereas the optical biometry AL measurement is to the pigment epithelium

Effect of Lens Geometry on IOL Position

Following the concept of Norrby [8] and taking the capsular bag equator position (EP) as a measure for the IOL position and considering small, medium, and long eyes, the schematic AL dependence is shown in Fig. 41.3. Small eyes have a shallower ACD with the capsular bag equator lying more anteriorly, while in long eyes, the lens lies deeper in the eye with the bag equator position more posteriorly.

This behavior is backed up by clinical findings on 15,123 eyes [9] (unpublished data) in Fig. 41.4. From preoperative high precision immersion ultrasound measurements of ACD (AC) and lens thickness (LT) as shown, the AL dependence of EP was deduced under the assumption EP = AC + 0.4*LT.

Figure 41.5 gives a schematic representation of the positions of the image principal planes of IOLs with different shape factors and geometry (here e.g., plano-convex and asymmetric biconvex) in eyes with different ALs. It is this posi-

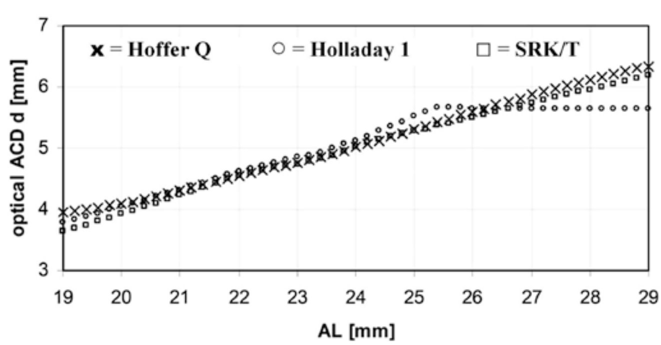

Fig. 41.2 Prediction curves for the optical ACD (d) in Eq. 41.1 for different theoretical formulas and an A constant of 118.0 (for SRK/T), equivalent to SF = 1.223 (for Holladay 1), and pACD = 4.97 (for Hoffer Q)

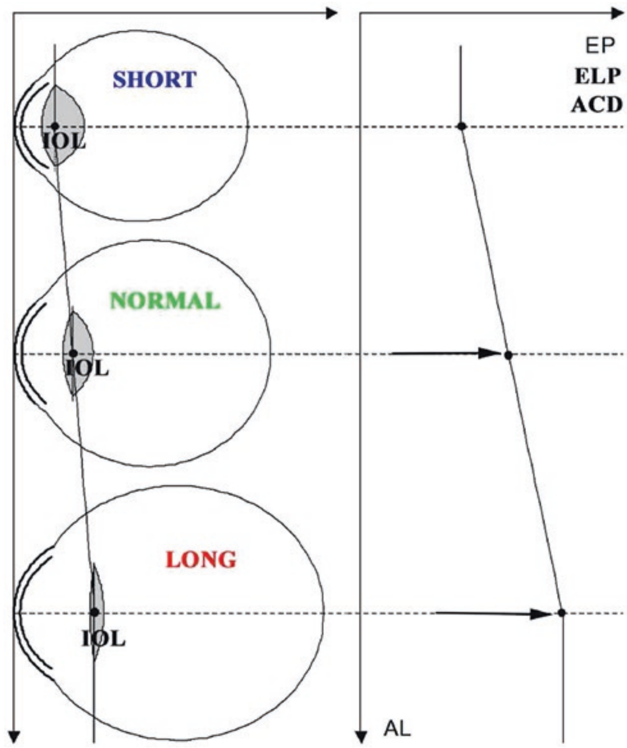

Fig. 41.3 Schematic of the dependence of the EP position of the capsular bag equator on the AL of the eye

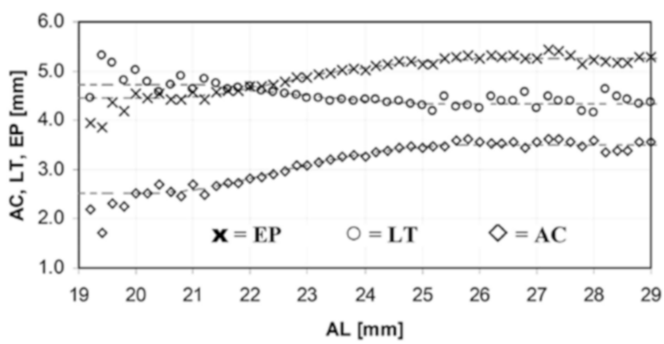

Fig. 41.4 Anterior chamber (AC), lens thickness (LT), and assumed position of the capsular bag equator position (EP) vs AL for 15,123 eyes. Data points: running means and assumption for EP: EP = AC + 0.4*LT

tion (of the image principal plane) that essentially determines d in Eq. 41.1. It is clearly evident from this that different IOLs are characterized by different AL dependencies of their optical ACDs. Thus, a curve (e.g., prediction of d vs AL) rather than a number (IOL constant) seems more useful for the characterization of an IOL.

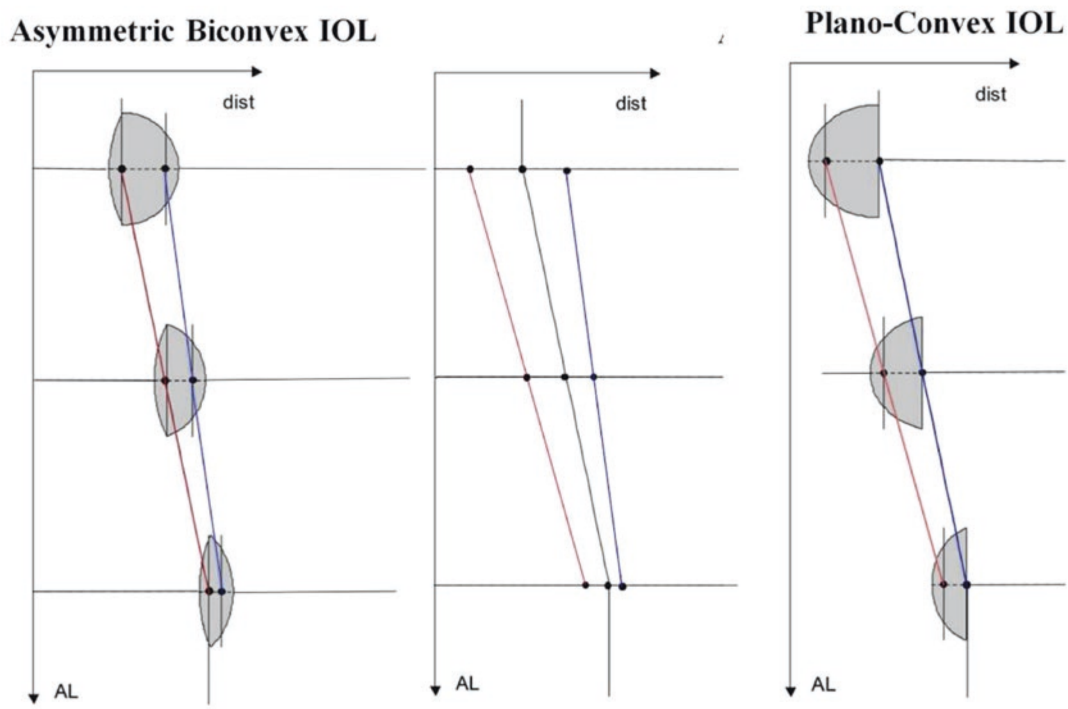

Fig. 41.5 Schematic representation of IOLs of different shape factors in eyes with different ALs (from short at the top to long at the bottom). The **red** lines near the **anterior vertex** and the **blue** near the **posterior vertex** of both the plano-convex and the biconvex IOL denote the positions of the image anterior and posterior principal planes, respectively, for the 2 IOL types

Calculations According to Haigis

Using the thick lens algorithm [10] for IOL calculation in the 1980s, we (like many others [11–13]) were looking for ways to predict the PO IOL position by means of multiple regression analysis performed on preoperative data [14]. We found the main contributions to the predictability of PO AC (ACpost) to stem from the AL and the preoperative ACD (AC) as shown in Table 41.2. Therefore, we predicted the (acoustically or optically) measurable PO ACD (ACpost) according to:

$$\mathbf{ACpost} = \mathbf{c_0} + \mathbf{c_1}^{*}\mathbf{AC} + \mathbf{c_2}^{*}\mathbf{AL} \quad (41.2)$$

The constants c_0, c_1, and c_2 were followed by a double linear regression analysis. Since the thick lens formula requires lens design data (e.g., radii of curvature, central thickness, and precise refractive indices) for every individual IOL power, which manufacturers are hesitant to release, we turned back again to the thin lens formalism of Eq. 41.1. This time, however, we applied the regression prediction to the optical ACD^A.

$$\mathbf{d}(\mathbf{Haigis}) = \mathbf{d} = \mathbf{a0} + \mathbf{a1}^{*}\mathbf{AC} + \mathbf{a2}^{*}\mathbf{AL} \quad (41.3)$$

The constants a0, a1, and a2 were found to be quite typical for a given IOL [15]. This led to the idea of using this set of numbers for the characterization of different IOLs.

$$\mathrm{ACpost} = \mathrm{a0} + \mathrm{a1}^{*}\mathrm{AC} + \mathrm{a2}^{*}\mathrm{LT} + \mathrm{a3}^{*}\mathrm{AL} + \mathrm{a4}^{*}\mathrm{CC} \quad (41.4)$$

Table 41.2 Correlation coefficient for the prediction of the measurable PO ACD using the formula

Parameter used for regression	AC	LT	AL	CC	AC, LT	AC, AL	AC,LT,AL	AC,LT,AL,CC
Correlation coefficient	68%	36%	44%	6%	68%	70%	70%	71%

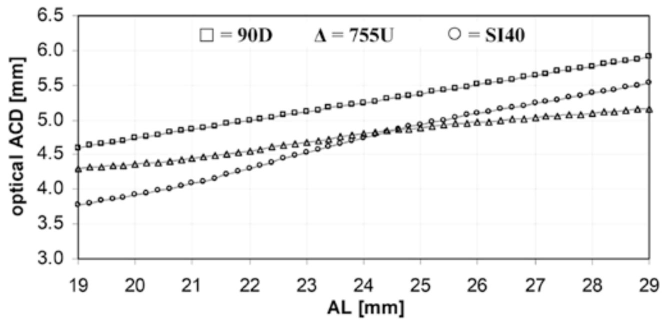

Fig. 41.6 AL dependence of the optical ACD d in Eq. 41.1 for IOL types 90D, 755 U, and SI40 for the Haigis formula with optimized lens constants. Note that the curves are different not only in the vertical position but also in the form

for plano-convex IOL type CILCO KR2U, where *AC* preoperative ACD, *LT* lens thickness, *AL* axial length, and *CC* corneal radius of curvature [14].

Olsen [12, 13] uses a similar regression approach with even more variables to predict PO IOL positions. However, apart from being characterized by their classical ACD constants, no further differentiation is made between different IOLs. Likewise, Holladay's IOL calculation program does not use more than one lens constant to characterize a given IOL.

An essential aspect of Eq. 41.3 lies in the fact that with three constants (a0, a1, and a2), it is possible to model the AL dependence of the optical ACD of a given lens, thus characterizing the IOL by a curve rather than a number. Since the preoperative ACD is dependent on AL (Fig. 41.4), d(Haigis), as defined by Eq. 41.3, is a function of the AL. The specific form of the resulting curve is determined by the specific values of a0, a1, and a2 (Fig. 41.6).

Generally, for a given lens, the numerical values of the three constants (a0, a1, and a2) are derived from a double regression analysis of d vs AC and AL, where d is the optical ACD producing the true PO refraction (see below). However, for this purpose, the PO data must be available. Prior to knowing this, an alternate method to determine a0, a1, and a2 is necessary.

It was found [16] that quite a number of IOLs could well be described by a fixed value of a1 = 0.4 and a2 = 0.1. Therefore, in "standard mode," we set a1 = 0.4 and a2 = 0.1 and derive a0 from the manufacturer ACD constant ACDconst according to:

$$\text{a0} = \text{ACDconst} - 0.40^{*}\,\text{meanAC} - 0.10^{*}\,\text{meanAL} \qquad (41.5)$$

where mean AC = 3.37 and mean AL = 23.39 [14].

Using the standard conversion between ACDconst and the A constant [6, 7] Eq. 41.5 is equivalent to:

$$\mathbf{a0 = 0.62467^{*}\,A - const - 72.434} \qquad (41.6)$$

Thus, the Haigis formula takes the form of Eq. 41.1, with d = d(Haigis) given by Eq. 41.3 and the additional substitutions $n_C = 1.3315$ and L = AL (from ultrasound or optical biometry).

Optimization of Constants

As long as PO results are not available to derive the three constants (a0, a1, and a2), the Haigis formula has to be used in the standard

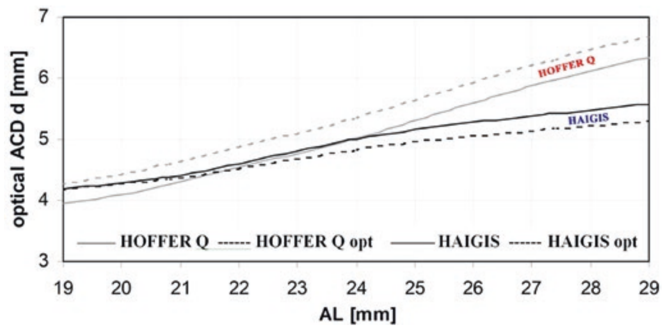

Fig. 41.7 AL dependence of the optical ACD d in Eq. 41.1 for IOL type 755 U and Haigis and Hoffer Q formulas using standard (solid lines) as well as optimized (dashed lines) lens constants. Note that optimization of the Hoffer Q constant results simply in a vertical curve shift, whereas in the Haigis algorithm, the curve *shape* is changed

mode, in which two of the three constants in formula 41.2 are set to the default values (a1 = 0.4 and a2 = 0.1) and the third constant (a0) is calculated from one of the classical lens constants (e.g., a pACD, SF or A constant) as given by the IOL manufacturer (see Eq. 41.5 or Eq. 41.6).

If, however, stable PO refraction results are at hand, it is possible to optimize the formula performance by personalizing all three Haigis lens constants. This may be done in two ways:

1. Only one constant is personalized, namely a0 or.
2. All three constants (a0, a1, and a2) are optimized.

Single Optimization (Optimization of a_0 Only)

If only a0 is optimized, then the situation is comparable to optimizing constants for other IOL formulas: there is only one number. In this case, a0 is iteratively adjusted until the mean prediction error (MPE) for a given set of patient records becomes zero, i.e.,

$$\mathbf{MPE} = \mathbf{Rx}_{\mathbf{true}} - \mathbf{Rx}_{\mathbf{calc}} = \mathbf{0} \quad (41.7)$$

Here, Rx_{true} denotes the spherical equivalent of the stable PO refraction at best corrected visual acuity (BCVA), and Rx_{calc} is the calculated refraction according to:

$$R_x = \frac{q - D_C}{1 + d_x \cdot (q - D_C)} \quad (41.8)$$

$$\text{where q is } q = \frac{n^*\left[n - D_L^*(L-d)\right]}{n^*(L-d) + d^*\left[n - D_L^*(L-d)\right]}$$

Optimizing (personalizing) the a0 is equivalent to shifting the curve, which describes the AL dependence of the optical ACD (d), up and down until a mean zero prediction error (Eq. 41.7) is reached (Fig. 41.7). This is very much like adjusting the pACD constant, the SF or the A constant in the other theoretical formulas. It has to be noted that in this case, one and the same d vs AL curve is used for all IOLs. After personalization (as just described), the theoretical formulas differ in the way a given IOL is represented by the formula-inherent d vs AL curve. However, one must remain aware that what may serve well for one type of IOL may not work for another IOL type (e.g., may differ in shape factor).

With the three constants approach, it is possible not only to adjust the position of the d vs AL curve but also to modify its shape. Thus, different IOLs may be characterized by different curves. The lens geometry is no longer built into the formula but is defined externally instead.

Triple Optimization (optimization of a_0, a_1, and a_2)

The optimization process, as has already been described, goes back to the time when Hoffer

[17, 18] correlated the ultrasound PO (pseudophakic) ACD with his preoperative ACD as well as when the AL was corrected by means of a double linear regression analysis. However, instead of using the ultrasonically determined acoustic ACD, the optical biometer ACD is now used for the regression analysis.

As a first step, for every patient record, the d value of the optical biometer ACD is calculated, which caused the measured PO refraction for the implanted IOL power. For this purpose, a quadratic equation for d is easily derived from the thin lens formula Eq. 41.1 by elementary algebraic transformations:

$$D_L{}^* d^2 - D_L{}^* \left(L + n/z\right) * d + n^* \left(L - n/z\right) + D_L{}^* L^* n/z = 0 \qquad (41.9)$$

with a quadratic equation solution: $d = \frac{1}{2 \cdot a} \cdot \left(-b - \sqrt{b^2 - 4 \cdot a \cdot c}\right)$

where $a = D_L$, $b = -D_L{}^*(L + n/z)$ and

$$c = \left[n^* \left(L - \frac{n}{z} \right) + D_L{}^* L^* \frac{n}{z} \right] \qquad (41.10)$$

Having calculated d for every patient record, a double linear regression analysis is performed with d being the dependent variable and AC and AL the independent variables. As a result, the constants a0, a1, and a2 are obtained such that equation $d = a0 + a1{*}AC + a2{*}AL$ is fulfilled.

Being aware that the optimization procedure determines the d vs AL curve, it is clear that the range of ALs for this analysis must be as broad as possible. It is of special importance to include ALs <21 mm and > 25 mm to cover the total range of available IOL powers. This implies that the analysis has to be based on a sufficiently large number of patients (a minimum >50). If only a small AL range would serve as a basis for optimization, good results naturally can only be expected for this very range while out-of-range ALs could lead to less accurate results.

Clinical Measurements

Methods

For an illustration of the formula performance and comparison with current power calculation algorithms, we retrospectively reviewed 990 patients implanted in the capsular bag with either:

1. A biconvex silicone plate lens [Chiron Adatomed 90D] $n = 118$,
2. A biconvex PMMA lens [Rayner 755 U] $n = 101$ or,
3. A biconvex silicone lens [Allergan SI40NB] $n = 771$.

Expected refraction was calculated using the formulas Haigis, Hoffer Q, Holladay 1, SRK II, and SRK/T and compared to the actually achieved stable PO refractions.

Results

First, the lens constants (as published by the manufacturers) were used for IOL power calculation; the results of which are shown in Table 41.3. The Haigis formula operating in non-optimized standard mode can be seen to produce slightly myopic results, whereas all other formulas end up on the hyperopic side. Clinically, it is always better to err on the slight myopic side than the hyperopic. The amount of deviation from target refraction differs from lens to lens. The SRK II results differ significantly from those of the theoretical formulas with respect to standard deviation as well as prediction percentages.

For each formula and IOL, individualized constants were subsequently calculated so as to produce a mean zero prediction error between actual and calculated refraction. Table 41.4 shows the results. Again, SRK II performs worse than the theoretic formulas, which produce good results. It is not possible to decide from this data which one of these actually is the

Table 41.3 Mean error (ME) between actual and calculated refraction (REF true-calc) using three IOL styles and percentages of refraction predictions within ±1.00 D and ± 2.00 D of error using manufacturer lens constants with each formula. The Haigis formula is used in "standard mode"

Standard	Rayner 755 U (*n* = 101)			Chiron 90D (*n* = 118)			Allergan SI40 (*n* = 771)		
Formula	ME [D]	% ± 2D	% ± 1D	ME [D]	% ± 2D	% ± 1D	ME [D]	% ± 2D	% ± 1D
SRK II	0.68 ± 0.74	95.0	71.3	0.82 ± 1.07	89.0	54.2	0.42 ± 0.73	96.8	82.9
SRK/T	0.53 ± 0.68	96.0	81.2	0.55 ± 0.82	94.9	70.3	0.29 ± 0.64	98.2	90.4
Holladay 1	0.46 ± 0.65	97.0	82.2	0.53 ± 0.77	95.8	72.0	0.24 ± 0.60	98.4	91.4
Hoffer Q	0.48 ± 0.65	97.0	84.2	0.56 ± 0.74	95.8	76.3	0.29 ± 0.60	98.7	91.2
Haigis	−0.21 ± 0.67	100	87.1	−0.28 ± 0.75	97.5	78.0	−0.38 ± 0.60	98.2	87.3

Table 41.4 Mean error (ME) between actual and calculated refraction ($REF_{true-calc}$) and percentages of refraction predictions within ±1.00 D and ± 2.00 D, if optimized constants were used with each formula. Haigis*1: single optimization (only a0 optimized); Haigis*3: triple optimization (all 3 constants optimized)

Optimized	Rayner 755 U (*n* = 101)			Chiron 90D (*n* = 118)			Allergan SI40 (n = 771)	
Formula	ME [D]	% ± 2D	% ± 1D	ME [D]	% ± 2D	% ± 1D	% ± 2D	% ± 1D
SRK II	0.00 ± 0.75	98.0	85.1	0.00 ± 1.07	94.1	66.9	97.8	86.4
SRK/T	0.00 ± 0.64	100.0	88.1	0.00 ± 0.77	97.5	83.9	98.3	90.7
Holladay 1	0.00 ± 0.63	100.0	86.1	0.00 ± 0.73	98.3	86.4	98.8	92.6
Hoffer Q	0.00 ± 0.65	100.0	88.1	0.00 ± 0.72	99.2	83.9	99.1	91.4
Haigis*1	0.00 ± 0.66	99.0	87.1	0.00 ± 0.76	98.3	81.4	98.7	92.5
Haigis*3	−0.04 ± 0.63	100.0	87.1	−0.01 ± 0.72	99.2	83.9	99.1	93.0

Table 41.5 Mean absolute error (MAE) between actual and calculated refraction ($REF_{true-calc}$) before and after optimization of constants for each formula in three IOL groups

MAE	Rayner 755 U (*n* = 101)		Chiron 90D (*n* = 118)		Allergan SI40 (*n* = 771)	
Formula	MAE ± SD Pre Opt	MAE ± SD Post Opt	MAE ± SD Pre Opt	MAE ± SD Post Opt	MAE ± SD Pre Opt	MAE ± SD Post Opt
SRK II	0.81 ± 0.59	0.56 ± 0.49	0.82 ± 1.07	0.83 ± 0.67	0.63 ± 0.56	0.52 ± 0.52
SRK/T	0.66 ± 0.55	0.50 ± 0.41	0.77 ± 0.61	0.60 ± 0.48	0.51 ± 0.48	0.44 ± 0.44
Holladay 1	0.61 ± 0.51	0.48 ± 0.41	0.72 ± 0.59	0.56 ± 0.47	0.48 ± 0.44	0.42 ± 0.42
Hoffer Q	0.62 ± 0.51	0.50 ± 0.41	0.72 ± 0.58	0.54 ± 0.47	0.50 ± 0.44	0.43 ± 0.42
Haigis*1	0.56 ± 0.41	0.52 ± 0.41	0.65 ± 0.46	0.58 ± 0.49	0.54 ± 0.47	0.42 ± 0.42
Haigis*3	------	0.49 ± 0.40	------	0.54 ± 0.48	------	0.42 ± 0.42

"best" formula since a possible ranking would change from IOL to IOL. The Haigis opt3 (with all three constants optimized) obviously performs better than Haigis opt1 (with only a0 optimized) and compares favorably to the other formulas. In general, it is evident from Tables 41.3 and 41.4 that individualization of lens constants results in a better performance of all formulas.

When comparing different algorithms, it is essential to consider not only the mean prediction error (ME) but also the mean absolute error (MAE)[1]. Table 41.5 shows the MAE before and after optimization of constants. For all formulas, the MAEs are also reduced by constant personalization while, again, the SRK II ranks last, and Haigis opt3 can be found in the top group.

For IOL 755 U, optimization yielded values between 117.68 and 118.84; for IOL 90D, optimization values were between 118.31 and 119.73, and for IOL SI40NB, values were from 117.55 to 118.52. Thus, in terms of A constants, optimization led to changes in them of the order of ~1.20 D for the 755 U, ~1.40 D for the 90D, and ~ 1.00 D for the SI40NB. The slopes (m) will be discussed below.

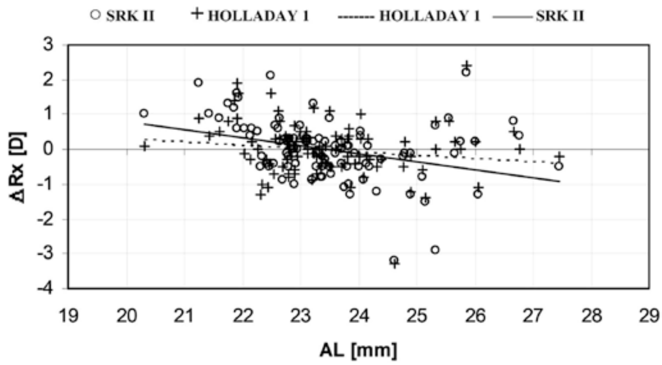

Fig. 41.8 AL dependence of the prediction error ΔRx (= Rx_{true}−Rx_{calc}) between actual and calculated PO refraction with IOL type 755 U for the Holladay 1 and SRK II formulas with optimized lens constants

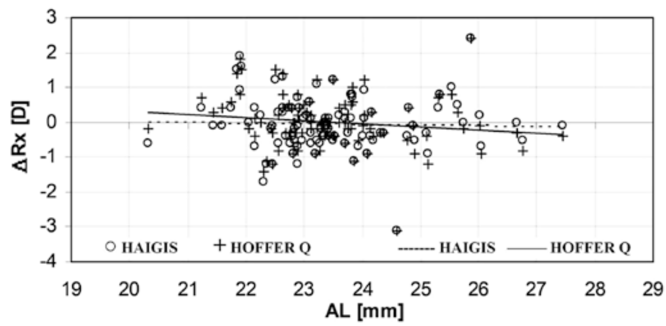

Fig. 41.9 AL dependence of the prediction error ΔRx (= Rx_{true}−Rx_{calc}) between actual and calculated PO refraction with IOL type 755 U for the Haigis and Hoffer Q formulas with optimized lens constants

Table 41.6 Summary of the optimized lens constants found and translated into A constants for ease of comparison and slopes of the regression line y = m x + t describing the AL dependence of the prediction error $\Delta REF_{true\text{-}calc}$ between actual and calculated PO refraction for different IOL formulas. The smaller the slope (m): the smaller the AL dependent error of refraction prediction

Optimized	Rayner 755 U (*n* = 101)		Chiron 90D (*n* = 118)		Allergan SI40 (*n* = 771)	
Formula	opt A-con	Slope	opt A-con	Slope	opt A-con	Slope
SRK II	118.84	−0.29	119.73	−0.56	118.52	−0.20
SRK/T	118.61	−0.16	119.29	−0.15	118.33	−0.05
Holladay 1	118.59	−0.13	119.33	−0.14	118.31	−0.01
Hoffer Q	118.59	−0.11	119.35	−0.06	118.36	+0.05
Haigis*1	117.76	−0.09	118.40	−0.06	117.57	+0.03
Haigis*3	117.68	0.00	118.31	−0.01	117.55	0.00

where *opt A-con* optimized A constant. A constants used: 755 U (118.0), 90D (118.7), and SI40 (118.0)

Minimizing refraction errors should not only produce a mean error of zero but ideally a zero prediction error for all ALs. It may well be that equal errors of opposite signs for long and short eyes cancel each other out, thus still producing an average of zero. Therefore, it is important to check the AL dependence of the prediction error ΔRx (= Rx_{true}−Rx_{calc} = ME). The slopes of the respective regression lines should be as close to zero as possible to indicate an AL-independent behavior. For lens 755 U, Fig. 41.8 shows the prediction error ΔRx between actual and calculated PO refraction vs AL with optimized constants for SRK II and Holladay 1 and Fig. 41.9 for the Hoffer Q and Haigis formulas. The respective slopes (m) for all formulas and all IOLs are also summarized in Table 41.6. It clearly follows from these findings that the "single-constant-formulas" (Hoffer Q, Holladay 1, SRK II and SRK/T) "pay a price" for a mean zero error with

Table 41.7 Mean absolute prediction errors (MAEs) in different AL ranges for 2 IOLs (Alcon MA60BM and SA60AT) using current IOL power formulas

AL	Haigis	Hoffer Q	Holladay 1	Holladay 2	SRK/T
20–21.99	0.25	0.25	0.25–0.50,	0.25	**0.51–1.00.**
22–24.49	0.25	0.25	0.25	0.25	0.25
24.50–25.99	0.25	0.25	0.25	0.25	0.25
26–28	0.25	0.25–0.50,	0.25	0.25	0.25
28–30	0.25	0.25–0.50,	0.25	0.25	0.25–0.50,
Minus power IOLs	0.25	**Not recommended**	0.25–0.50,	0.25	**0.51–1.00.**

non-zero prediction errors in short and long eyes. The largest is for the SRK II and the least is for the Hoffer Q. The better performance of the Haigis algorithm as indicated in the zero slopes stems from using three IOL constants instead of just one as pointed out earlier.

We see here the AL dependence of the optical ACD (d) for the Hoffer Q and Haigis formulas in standard and optimized modes (for lens 755 U). These graphs may be compared to Fig. 41.2 (which is based on the respective standard constants). For the plot characterizing the Haigis calculation, which makes use of AC in addition to AL (see Eq. 41.5), the model dependence of Fig. 41.4 was used. Optimization causes a vertical translation of the standard Hoffer Q curve, whereas, in the Haigis algorithm, the shape of the curve is altered. Thus, it is possible to create an individual curve shape for a given lens as opposed to the standard shape used in the other formulas.

Accordingly, different IOLs represented by different sets of constants a0, a1, and a2 will have different d vs AL curves, as is shown in Fig. 41.6 for our 3 IOLs: each one is individually positioned, with individual shape.

Once properly optimized (over a large range of ALs), the three constants approach allows good results irrespective of AL. This has also been observed by others, as Table 41.7 shows.

In Summary

The Haigis formula is based on thin lens optics just as does the Hoffer Q, Holladay 1, and SRK/T. In this respect, it makes use of the elementary basic thin lens formula. It does not compare to SRK I/II, which are purely empirical. However, while all other formulas use only one constant (the pACD constant, the SF, or the A constant) for a given IOL, the Haigis formula uses three (a0, a1, and a2). In addition, apart from the AL, the ACD is taken to serve as a predictor for the PO IOL position. By this approach, it is possible to represent an IOL by a curve (optical ACD vs AL) rather than just a single number. The three constants can be derived from a statistical analysis of PO results for a sufficient number of patients (minimum >50) supplied for a given IOL.

In the standard mode, i.e., as long as this optimization process has not been carried out yet, two of the three constants of the Haigis formula are set to default values (a1 = 0.4 and a2 = 0.1), whereas the third constant (a0) is derived from one of the classical lens constants. (e.g., A constant) given by the IOL manufacturer. Therefore, in default mode, the Haigis formula is "just another theoretical formula," which, in general, has a slightly better performance for long and short eyes due to the fact that the clinical experience in the formula-inherent prediction curves stems from more recent IOLs as compared to other IOL formulas.

The power of the Haigis formula evolves after optimization, i.e., individualization of constants, as it allows a mean zero prediction error for the PO refractions irrespective of AL. There are two optimization modes:

1. Classical optimization on the basis of 1 constant, which is inherent in other theoretical

formulas: to individualize the constant of a specific IOL. The constant under question is iteratively changed to achieve a mean zero prediction error for the postop refraction. However, a mean zero error might be due to balanced errors in short and long eyes. Generally, the smallest AL-dependent errors were found with the Haigis formula.

2. Optimization of three constants: in this case, the constants a0, a1, and a2 are derived from a statistical analysis of PO results. The range of ALs for this analysis should be as broad as possible. Thus, for every IOL, an individual curve is defined for optimum prediction of the PO IOL position allowing a mean zero prediction error for all ALs.

Performance of the Haigis formula with no personalization (optimization) is as good or bad as the other theoretical formulas, and with optimization of 1 constant, it is often better for short and long eyes. When all three constants are optimized, performance is better for all ALs and all IOL types.

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