ARTICLE

Intraocular lens power calculation and optimized constants for highly myopic eyes

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PURPOSE: To determine the accuracy of intraocular lens (IOL) power calculations in eyes with high myopia and to suggest adjusted constants for these cases.

SETTING: Centre for Ophthalmology, Eberhard-Karls-University, Tuebingen, Germany.

METHODS: Patients with high myopia having phacoemulsification with implantation of an AcrySof MA60MA IOL (power range +5.00 to −5.00 diopters [D]) were evaluated. Optical biometry (IOLMaster) and IOL calculations were performed before and after IOL implantation. Because of different optic principal planes of negative-diopter and positive-diopter IOLs, separate constants were calculated for these groups.

RESULTS: Fifty eyes (32 patients) were evaluated. Thirty eyes (mean AL 31.15 mm ± 1.69 [SD]) had implantation of a positive-diopter IOL (mean power +3.10 ± 1.50 D) and 18 eyes (mean AL 33.20 ± 2.25 mm), a negative-diopter IOL (mean power −3.20 ± 1.70 D). Postoperatively, the mean spherical equivalent was −1.42 ± 1.33 D and −0.41 ± 1.81 D, respectively. The difference in optimized constants between positive- and negative-diopter IOLs was significant for all formulas. Power calculation with the SRK II formula showed a wide range of deviation of postoperative refraction from target refraction. Calculation with the Haigis, SRK/T, Holladay 1, and Hoffer Q formulas showed a mean deviation of 0.00 D with an SD of 0.88, 0.92, 1.03, and 1.15, respectively.

CONCLUSIONS: Results indicate that the SRK II formula cannot be recommended for IOL power calculation in highly myopic patients. With optimized constants, the SRK/T, Haigis, Hoffer Q, and Holladay 1 formulas produced small deviation of postoperative refraction from target refraction.

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Accurate intraocular lens (IOL) power calculation in cataract surgery is essential to achieving the postoperative target refraction and high patient satisfaction. Possible sources of miscalculation with ultrasound biometry include errors in axial length (AL) determination (54%), corneal power measurement (8%), and postoperative anterior chamber depth (ACD) estimation (38%).[1] Since the advent of the IOLMaster optical biometer (Carl Zeiss Meditec), which measures AL by partial coherence interferometry (PCI), the accuracy of IOL calculation has improved significantly. It is now possible to predict the postoperative refractive outcome in eyes with IOLs of standard powers (6.00 to 28.00 diopters [D]) to an accuracy of ±0.50 D and ±1.00 D in 62.5% and 92.4% of cases, respectively, versus 45.5% and 77.3% with ultrasound biometry.[2] According to Preußner et al.,[3] AL measurement is no longer the most frequent error, nor is the corneal radius, in normal eyes. At present, the main error results from the unavoidable uncertainty of the postoperative position of the IOL. However, this error is less relevant clinically because it results in only minor deviation (mean ±0.35 D) from the target refraction.[3]

However, IOL power calculation remains challenging in highly myopic patients who require IOLs with a low-diopter power or even with negative-diopter power. Nearly all studies of this topic in the literature report a systematic deviation between the postoperative refraction and the target refraction. Highly myopic eyes have a high risk for postoperative hyperopia, a deviation from the target refraction that is reported to occur with ultrasound biometry[4–7] and PCI optical biometry,[8,9] which may minimize AL measurement errors resulting from posterior staphyloma (B.A.M. Lege, MD, W. Haigis, MD, "Laserinterferenz-Biometrie und konventionelle Ultraschallbiometrie in staphylomatösen Augen," presented at the 14. Kongreß der Deutschsprachigen Gesellschaft für Intraokularlinsen-Implantation und refraktive Chirurgie, Luzern, Switzerland, February

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2000. Abstract available at: http://www.dgii.org/2000/16.html. Accessed May 14, 2009). Apparently, this hyperopic refractive error cannot be avoided with more accurate AL measurement. Zaldivar et al.[7] found a systematic error even though they checked the A-scan measurements against B-scan ultrasound results.

This retrospective study evaluated whether the error in IOL calculation in highly myopic patients can be corrected with optimized constants. We also evaluated the predictability of different IOL power calculation formulas using the new constants.

PATIENTS AND METHODS

The records of all patients who had phacoemulsification with implantation of an AcrySof MA60MA acrylic IOL (Alcon, Inc.) between 2003 and 2007 were retrospectively reviewed. All patients had surgery at University Eye Hospital, Eberhard-Karls University, Tuebingen, Germany.

Excluded from analysis were eyes that had not had PCI optical biometry or that had pathology that might have affected the accuracy of biometry calculations (eg, retinal detachment surgery, corneal scars). Other exclusion criteria were severely reduced visual acuity (hand movements or worse) and unwillingness or inability to participate in the study. Glaucoma, amblyopia, or myopic degeneration was not an exclusion criterion; however, patients unable to participate in refraction because of 1 of these diagnoses were excluded.

All preoperative IOL calculations were performed with the IOLMaster (version 3.01.0294). Because there are no commonly accepted optimized constants for the AcrySof MA60MA IOL, the constants for the AcrySof MA60BM were used; this IOL has a similar optical design and the same constant for ultrasound biometry but a different available range of diopters. The constants were $a0 = 1.443$, $a1 = 0.077$, and $a2 = 0.163$ (Haigis formula); pACD = 6.08 (Hoffer Q formula); sf = 2.33 (Holladay 1 formula); A = 119.8 (SRK/T formula); and A = 120.4 (SRK II formula). In addition, to make allowances for the different geometries of positive-diopter IOLs and negative-diopter IOLs, 2 sets of constants were derived, 1 for each IOL power sign (Table 1).

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Table 1. Optimized constants for each formula for positive-diopter and negative-diopter IOLs.

Constant	Positive-Diopter IOL	Negative-Diopter IOL
Haigis *a*0	5.74	−4.01
SRK/T A	126.63	104.43
Holladay 1 sf	10.46	−6.48
Hoffer Q pACD	16.15	−4.86
SRK II A	119.47	120.09

IOL = intraocular lens

Experienced surgeons performed all operations using standard phacoemulsification through a 3.0 mm temporal clear corneal tunnel incision and a 5.0 to 5.5 mm capsulorhexis. Phacoemulsification was followed by in-the-bag implantation of the acrylic IOL.

All patients had 1 preoperative examination and, apart from the regular postoperative care, 1 final postoperative examination. In addition to a standard clinical examination (subjective refraction, corrected distance visual acuity), AL and corneal power were measured by PCI optical biometry once postoperatively. All objective measurements and subjective refractions were performed by the same specialist (K.P.).

Based on the postoperative refractive results, individualized IOL constants were calculated separately for the positive-diopter and negative-diopter ranges within the framework of the User Group for Laser Interference Biometry project to optimize constants for optical biometry (Available at: www.augenklinik.uni-wuerzburg.de/ulib. Accessed May 13, 2009). The need to treat plus and minus IOLs differently[10] for optimized outcomes is based on lens geometry changes during the transition from plus to minus diopters, with the lens' principal planes switching sides relative to the haptic plane. Because the positions of principal planes and the IOL constants are directly linked, different constants are required. (For an in-depth treatment of this effect, see Haigis.[10])

The estimated postoperative refractive outcome was reevaluated by inputting the new constants into the PCI biometer's calculation algorithm with the preoperative anatomic data. The deviation of the postoperative refraction from the target refraction using the new constants and the deviation using the old constants were compared with a paired *t* test.

All statistical analyses were performed with JMP IN software (version 5.1, SAS Institute, Inc.). One-way analysis of variance (ANOVA) was used to compare the preoperative anatomic data and postoperative refractive outcome in eyes with a positive-diopter IOL and eyes with a negative-diopter IOL. A *P* value less than 0.05 was considered statistically significant.

RESULTS

The records of 91 patients were reviewed. Excluded were 16 eyes that did not have PCI biometry, 9 eyes with pathology that could affect biometry calculation (7 eyes, retinal detachment surgery; 2 eyes, corneal scars), 2 eyes with severely reduced visual acuity, and 14 eyes of patients who were unwilling or unable to participate in the study. No patient was excluded for inability to participate in refraction. Thus, 50 eyes of 32 patients were included in the study. Thirty eyes received a positive-diopter IOL; 18 eyes, a negative-diopter IOL; and 2 eyes, a zero-diopter IOL. The mean patient age was 57.14 years ± 10.27 (SD) (range 35 to 77 years) and the mean follow-up, 18.92 ± 13.33 months (range 3 to 47 months). There were no statistically significant differences in the accuracy of the PCI biometry measurements between preoperatively and postoperatively.

Table 2 shows the preoperative biometry measurements and postoperative outcomes by IOL power. The AL was statistically significantly longer in eyes with a negative-diopter IOL than in eyes with a positive-diopter IOL (P = .0025, ANOVA). The differences between the 2 groups in keratometry (K) readings, ACD, postoperative SE, and postoperative astigmatism were not statistically significant (P>.05, ANOVA). Figure 1, *A* and *B*, shows the distribution of the AL and the implanted IOL power. Table 3 shows the distribution of the AL, ACD, and K values in all eyes. The IOL power and corneal power (K readings) were correlated with AL, while ACD was not (Figure 1, *C* to *E*).

Figure 2, *A* to *E*, shows the deviation of the postoperative refraction from the target refraction (difference between postoperative SE and calculated postoperative refraction) for all formulas using the old constants and using the optimized constants. In 18 eyes, the ACD was not measured preoperatively; therefore, the target refraction was calculated using the Haigis formula in 32 eyes (18 positive-diopter IOL; 14 negative-diopter IOL). For the other formulas, the target refraction was calculated for all eyes.

The deviation of the postoperative refraction from the target refraction of the SRK II formula spanned a wide range of diopters and was correlated with AL (Figure 2, *E*). The deviation of the postoperative refraction from the target refraction with the Haigis, SRK/T Holladay I, and Hoffer Q formulas was not correlated with AL; however, these formulas inferred a postoperative hyperopic refraction, as shown by the mean values given in Figure 2, *A* to *E*. The deviation was

Table 2. Preoperative biometry and postoperative outcomes.

	Group		
Parameter	Positive-Diopter IOL (n = 30)	Negative-Diopter IOL (n = 18)	Zero-Diopter IOL (n = 2)
AL (mm)†	31.15 ± 1.69	33.20 ± 2.25	31.37 and 35.34
K value (mm)	7.56 ± 0.28	7.71 ± 0.33	7.60 and 8.34
ACD (mm)	3.72 ± 0.11	3.59 ± 0.12	NE
Implanted IOL power (D)	3.10 ± 1.50	−3.20 ± 1.70	0.00
Postop SE (D)			
Mean ± SD*	−1.42 ± 1.33	−0.41 ± 1.81	−0.25 and −0.62
Range	−3.94 to +1.00	−4.18 to +2.53	—
Postop astigmatism (D)			
Mean ± SD*	1.42 ± 0.71	1.38 ± 0.63	2.50 and 0.75
Range	0.50 to 2.75	0.00 to 2.50	—
Deviation from target refraction (D)			
Old constants			
Haigis†	+0.57 ± 0.18	+1.14 ± 0.21	0.79 and 1.37
SRK/T†	+0.59 ± 0.15	+1.68 ± 0.19	1.02 and 1.49
Holladay 1	+1.10 ± 0.14	+1.64 ± 0.18	1.32 and 1.83
Hoffer Q†	+1.25 ± 0.14	+2.10 ± 0.19	1.65 and 2.18
SRK II	−0.94 ± 0.38	−0.32 ± 0.49	−1.75 and +4.28
New constants			
Haigis	0.00 ± 0.21	0.00 ± 0.24	0.79 and 1.37
SRK/T	0.00 ± 0.17	0.00 ± 0.21	1.02 and 1.49
Holladay 1	0.00 ± 0.18	0.00 ± 0.24	1.32 and 1.83
Hoffer Q	0.00 ± 0.26	0.00 ± 0.20	1.65 and 2.18
SRK II	0.00 ± 0.38	0.00 ± 0.49	+0.95 and −5.82

ACD = anterior chamber depth; AL = axial length; IOL = intraocular lens; K = keratometry; NE = not evaluated; SE = spherical equivalent
*Excluding zero-diopter group, for which only the means of the 2 eyes are given
†Statistically significant difference between positive-diopter group and negative-diopter group

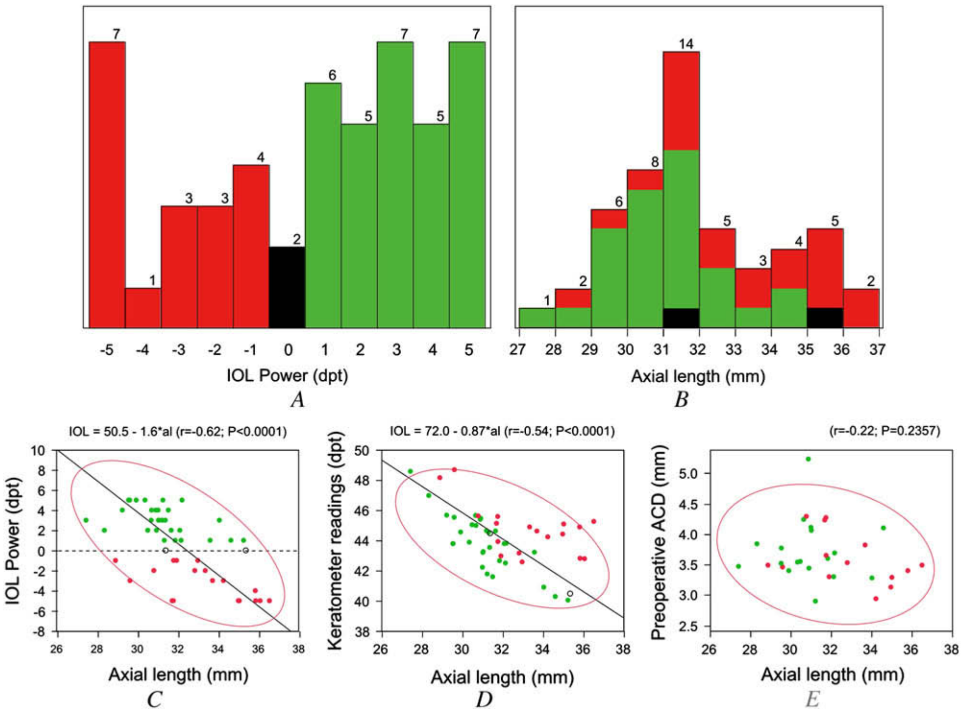

Figure 1. *A* and *B*: Distribution of AL and IOL power. The red columns depict the eyes with a negative-diopter IOL; the green columns, eyes with a positive-diopter IOL; and the black columns, eyes with a zero-diopter IOL. *C* to *E*: Correlation of IOL power, corneal power, and preoperative ACD with AL. The red oval outlines represent the bivariate 95% confidence intervals. The red circles depict the eyes with a negative-diopter IOL; the green circles, eyes with a positive-diopter IOL; and the open circles, eyes with a zero-diopter IOL (IOL = intraocular lens).

higher in the eyes with a minus-diopter IOL and was statistically significantly different from the deviation in eyes with a plus-diopter IOL for the Haigis, the Holladay 1, and the SRK/T formulas (Table 2).

Figure 2, *F* to *I*, shows the mean deviation of the postoperative refraction from the target refraction using the 2 sets of constants. Thirty-two eyes (84.4%), 50 eyes (76.0%), 50 eyes (68.0%), and 50 eyes (66.0%) were within a ±1.00 D of the target refraction using the Haigis, SRK/T, Holladay 1, and Hoffer Q formulas, respectively. The difference in the deviation from the target refraction with the new constants was statistically significantly different from the deviation with the old constants for the Haigis, the SRK/T, Holladay 1, and Hoffer Q formulas ($P < .0001$, paired t test). Although the mean deviation with the SRK II formula could be corrected with optimization of the constants (Figure 2, *J*), it was still dependent on AL and ranged from −4.83 to +5.10 D. With this formula, 44% of eyes were within ±1.00 D of the target refraction.

Table 3. Distribution of AL, K, and ACD values.

Parameter	AL (mm)	K (mm)	ACD (mm)
Mean	31.97	7.67	3.67
Standard deviation	2.14	0.327	0.47
Maximum	36.51	8.43	5.23
Minimum	27.42	6.94	2.90
Median	31.57	7.62	3.54
5% quantile	29.03	7.09	3.04
25% quantile	30.70	7.48	3.40
75% quantile	33.51	7.85	3.90
95% quantile	35.82	8.30	4.28

ACD = anterior chamber depth; AL = axial length; K = keratometry

DISCUSSION

In our study, there was a postoperative hyperopic refractive error with all formulas tested, as described in the literature.[4–9] There are no reports in the literature regarding the cause of this error other than that by Haigis.[10] Using model calculations, Haigis identified the use of plus-power IOL constants for both positive-diopter IOLs and negative-diopter IOLs as a source of hyperopic refractive error. Improvement in the accuracy and reliability of AL measurement with PCI biometry did not eliminate the error.[9] It also seems to be independent of the estimation of postoperative ACD because miscalculation of ACD does not greatly affect postoperative refraction with low-diopter IOLs.[11] A hyperopic refractive error occurs even in eyes with zero-diopter IOLs even though ACD is not used in calculations for these IOLs.[8]

The correlation of anatomic parameters, such as AL, ACD, and K readings, might play an important role in the hyperopic error. In emmetropic eyes, the mean ACD increases and the corneal power decreases with increasing AL, while in highly myopic eyes (AL >25.84 mm), this correlation is inverted and smaller

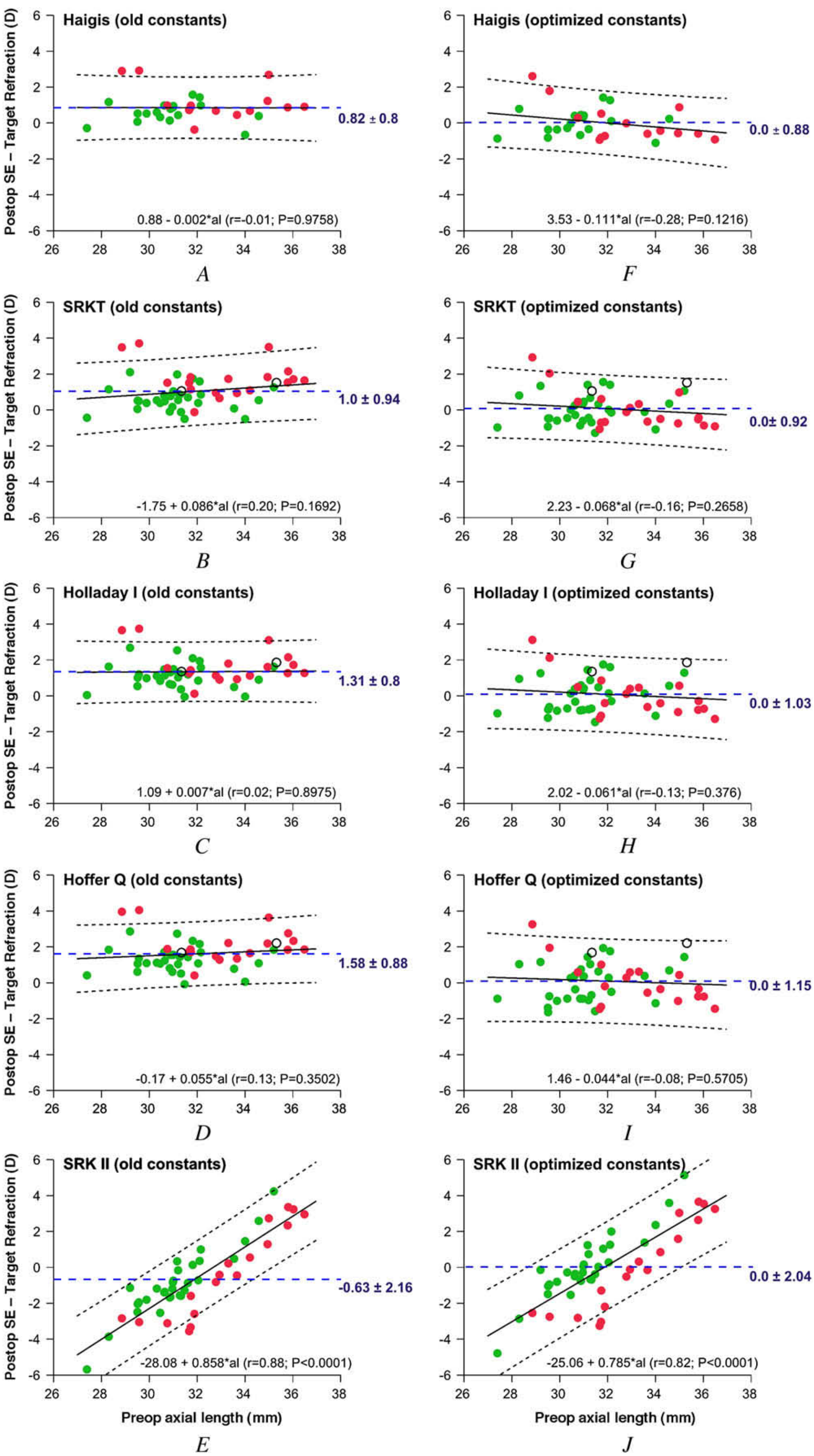

Figure 2. Deviation of the postoperative refraction from the target refraction for each formula eye in relation to AL. *A* to *E*: Old constants. *F* to *J*: Optimized constants. The red circles depict the eyes with a negative-diopter IOL; the green circles, eyes with a positive-diopter IOL; and the open circles, eyes with a zero-diopter IOL. The broken blue lines represent the mean deviation and the black lines, the linear regression with the confidence intervals (*broken black lines*) (SE = spherical equivalent).

than in normal eyes (P.C. Hoffmann, MD, "Biometrieergebnisse von 23239 Augen," presented at the 22nd Kongreß der Deutschsprachigen Gesellschaft für Intraokularlinsen-Implantation und refraktive Chirurgie, Heidelberg, Germany, February 2008; abstract available in Klin Monatsbl Augenheilkd 2008; 225[suppl 1]:S10). In our series, we found a correlation between the K reading and AL but no correlation between ACD and AL. Our patient cohort might have been too small to show the inverted correlation between AL and ACD; however, that there may be a lack of correlation might have an important influence on IOL calculation. Although in our study the K readings and AL were correlated, in daily routine the refractive power of the cornea is calculated using the K readings of the anterior surface and the constant 1.3375, which should include the negative refractive part of the posterior surface. For IOL calculation, the relation of the anterior surface and posterior surface in highly myopic eyes should be the same as in emmetropic eyes, but whether this is the case remains unclear.

The IOL design, or its shape factor, also has an influence on postoperative refraction.[3] The anatomic position of an IOL does not reflect the principal optic plane of the IOL. If an IOL is not symmetrically biconvex, this principal plane can vary with different diopters. This may affect IOL calculation.[3] The optic of the IOL we used is a meniscus and, according to the manufacturer, the "design varies with diopters" (Available at: http://www.alcon-pharma.de/downloads/Optimierte%20IOLKonstanten-071011.pdf/at_download/file. Accessed May 13, 2009). In fact, negative-diopter IOLs are concave, while positive-diopter IOLs are convex. Thus, we considered negative-diopter and positive-diopter IOLs to be 2 different IOLs that required separate constants. In a theoretical analysis, Haigis[10] showed why it is necessary to treat the 2 types of IOLs differently; that is, the principal plane of low-power IOLs is far from the geometric IOL position and switches sides when the IOL power sign is changed. Thus, the respective optimized constants differ significantly between positive-diopter IOLs and negative-diopter IOLs. We recommend using these constants for all IOLs with low positive or low negative power.

By optimizing the constants separately for positive and negative IOLs, we corrected the hyperopic deviation from the target refraction for the Haigis, SRK/T, Holladay 1, and Hoffer Q formulas. Using the constants, 84.4%, 76%, 68%, and 66% of eyes, respectively, were within ±1.00 D of the target refraction. In other studies using ultrasound biometry, 66.6%[4] and 69.0%[12] of highly myopic eyes and 77.3% of emmetropic eyes[2] were within ±1.00 diopter of the target. The predictability in emmetropic eyes increased significantly when PCI optical biometry was used, with 92.4% of eyes within ±1.00 D.[2] However, the IOL we used, as with most low-diopter and negative-diopter IOLs, is only available in 1.00 D steps, which hinders comparison of the accuracy of IOL calculation between emmetropic eyes and highly myopic eyes.

In our study, use of the optimized constants corrected the mean deviation of the postoperative refraction from the target refraction with the SRK II formula; however, the deviation was still dependent on AL and spanned a range of 9.93 D. In a 1990 study, Kora et al.[11] analyzed the AL-dependent deviation with linear regression and recommended a modified SRK II formula. However, subsequent studies,[5,9] including one by Sanders et al.,[13] recommend not using the SRK II formula in highly myopic eyes.

It is interesting that the 2 patients in our study with a zero-diopter IOL, in which case IOL position does not affect postoperative refraction, had a hyperopic deviation from the postoperative target refraction using all formulas. MacLaren et al.[8] report 9 highly myopic patients with zero-diopter IOLs who had a mean deviation of 0.80 ± 0.36 D using the SRK/T formula. However, the deviation was not statistically significant and suggested greater accuracy than with negative-diopter or positive-diopter IOLs. Zaldivar et al.[7] report 1 patient with a zero-diopter IOL and a +2.74 D deviation from the target refraction.

From the analysis of Haigis,[10] it follows that a zero-diopter IOL typically causes a hyperopic error on the order of 0.25 D. The beam of light is widened somewhat by a zero-diopter IOL, which causes the focal point to be slightly behind the retina and thus results in a hyperopic error.

Additional data from patients with zero-diopter IOLs would help in determining whether other sources of error contribute to the tendency toward hyperopic deviation from target refraction in highly myopic patients. Because postoperative IOL position is excluded as a source of error in eyes with zero-diopter IOLs, additional studies could provide insight into the accuracy of classic IOL formulas in highly myopic eyes.

In conclusion, the refractive outcomes in highly myopic eyes after cataract surgery could be significantly improved by optimizing the constants for negative-diopter and positive-diopter IOLs separately. We recommend optimizing all constants for low-power (−5.00 to +5.00 D) IOLs in this manner. Our results indicate that the Haigis and SRK/T formula are the most accurate for highly myopic eyes. However, even with optimized constants, IOL power calculation for highly myopic eyes is not as predictable as for emmetropic eyes.

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