Intraocular lens power calculations in patients with extreme myopia

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ABSTRACT

Purpose: To determine the variables that might contribute to improved intraocular lens (IOL) power calculations preoperatively in cataract patients with extreme myopia.

Methods: This retrospective study included 50 patients with extreme myopia and axial lengths longer than 27.0 mm. All patients had clear corneal phacoemulsification by the same surgeon and implantation of the Domilens SiFlex 1 IOL (power range −6.0 to +5.0 diopters [D]). The performances of the SRK/T, Hoffer Q, Holladay 1, and Holladay 2 formulas in predicting an IOL power that would meet the target refraction of ±1.00 D were compared.

Results: The formulas tended to suggest underpowered IOLs, more severe in eyes with axial lengths greater than 30.00 mm. These eyes accounted for most of the minus-power IOLs implanted. Back calculations of axial lengths in patients with minus-power IOLs showed that, on average, emmetropia could have been predicted by choosing shorter axial lengths (up to 2.72 mm shorter) than those used in the original IOL power calculations. Preoperative B-scan ultrasonography demonstrated the presence of a posterior pole staphyloma temporal to the optic nerve in several patients who required minus-power IOLs, which suggests that axial length measurement problems were a major source of IOL calculation errors in these patients.

Conclusions: In eyes with axial lengths longer than or equal to 27.0 mm, current third- and fourth-generation lens calculation formulas have a tendency to over minus patients between −1.0 and −4.0 D. The formulas appear to perform better for plus-power IOL implantation than for minus-power IOL implantation. The use of B-scan ultrasonography to locate posterior pole staphylomas may improve the accuracy of IOL calculations in eyes with extreme myopia. *J Cataract Refract Surg 2000; 26:668–674* © 2000 ASCRS and ESCRS

Intraocular lens (IOL) power calculations pose difficulties for cataract surgeons planning surgery in eyes with extreme myopia.[1–7] We present the results of a retrospective study of IOL power calculations in patients with extreme myopia who had clear corneal phacoemulsification and IOL implantation by the same surgeon. We compare the performance of 4 formulas in predicting a target refractive error of ±1.00 diopter (D).

Accepted for publication January 14, 2000.

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None of the authors has a financial interest in any product mentioned.

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Patients and Methods

Fifty patients with extreme myopia and axial lengths longer than 27.0 mm had cataract extraction with IOL implantation between April and October 1996. Their charts were reviewed retrospectively. Preopera-

Published by Elsevier Science Inc.

0886-3350/00/$–see front matter
PII S0886-3350(00)00367-9

Orig. Op.	OPERATOR:	Session	PROOF:	PE's:	AA's:	COMMENTS	ARTNO:

tive examinations included uncorrected visual acuity, best corrected visual acuity, slitlamp biomicroscopy, applanation tonometry, and dilated indirect ophthalmoscopy. Automated keratometry and computerized corneal topography were also performed.

A-scan ultrasonography was performed using the Humphrey ultrasonic biometer (velocity 1545 m/second). Because the velocity used in long eyes should be closer to that used in the aphakic eye (1532 m/second), it is recommended that the axial lengths be measured at, or converted to a distance for, 1532 m/second (AL_{1532}), to which a nominal value of 0.28 mm is added to obtain the true ultrasonic axial length (AL_U).[8] Using Holladay's technique for accurate axial length measurements in long eyes,[9,10] values leading to minimal changes in axial length between these 2 velocity measurements were calculated.

$$AL_{1532} = AL_{1545} \times (1532/1545)$$

$$AL_U = AL_{1532} + 0.28 \text{ mm}$$

As an example,

$$AL_{1532} = AL_{1545}\,(28.00 \text{ mm}) \times (1532/1545) + 0.28 \text{ mm} = 28.04 \text{ mm}$$

This is a negligible difference.

$$AL_{1532} = AL_{1545}\,(35.00 \text{ mm}) \times (1532/1545) + 0.28 \text{ mm} = 34.98 \text{ mm}$$

This is also a negligible difference.

Preoperative IOL calculations were performed using the SRK/T, Hoffer Q, and Holladay 1 formulas with the Hoffer Programs version 1.5 software. Holladay 2 calculations were performed retrospectively using the Holladay IOL Consultant version 1.0 software. Staff physicians and technicians at Instituto Zaldivar prepared all preoperative data. The results were reviewed by 1 author (R.Z.).

Final IOL power selections were based on the personal experience of 1 author (R.Z.) after examining the patient data and recommended IOL powers derived from the SRK/T, Hoffer Q, and Holladay 1 formulas. The goal in IOL selection was a lens power that would yield a postoperative refraction nearest to plano, erring on the side of myopia. The IOL model implanted in all patients was the Domilens SiFlex 1, which is only available in full diopter increments in the power range evaluated in this study.

Cataract surgery was performed through a 3.2 mm temporal clear corneal incision with standard phacoemulsification techniques using the AMO Prestige phacoemulsification system. The incision was enlarged to 5.0 mm to insert the single-piece poly(methyl methacrylate) Domilens SiFlex 1 IOL. A single 10-0 nylon suture was used to close the wound. Patients were examined 1 day and 1 month postoperatively. Postoperative refractions were obtained at each patient's final visit.

Using the actual IOL implanted and the corresponding postoperative spherical equivalent (SE), the IOL power that would have produced the target refraction (SE of $\pm$1.00 D) was determined. These calculations are termed the empiric ideal IOL and the empiric ideal SE, based on the mean incremental change predicted by the 4 formulas. AQ: 3

Although we recognize that the relationship between IOL power and refractive error is a function of lens power, corneal power, and their separation, for simplicity we used a conversion factor of 0.50 D. Using a reciprocal ratio (refraction/IOL), this value varies from 0.5 to 1.0 D in the IOL power range discussed. Knowing that axial lengths are longer than the distance to the macula in this group of patients, we chose to simplify the mathematical variables and use the lower ratio.

For example, if a -4.00 D lens was implanted and yielded a refraction of -1.00 D SE (1.00 D of undercorrection), we calculated that a -6.00 D IOL would have yielded a plano postoperative SE. (In this case, the empiric ideal IOL would be -6.0 D and the empiric ideal SE, 0.0 D.)

A "Δ-Diopter" value was calculated by subtracting the empiric ideal IOL power from the IOL power suggested by the 4 formulas:

$$\Delta\text{-Diopter} = \text{Suggested IOL Power} - \text{Empiric Ideal IOL Power}$$

A Δ-Diopter for the surgeon's choice of IOL power was also calculated:

$$\Delta\text{-Diopter (actual)} = \text{Actual IOL Power} - \text{Empiric Ideal IOL Power}$$

Based on the empiric ideal IOL and SE, the "postoperative predicted SE" for each formula's suggested IOL was calculated:

Postoperative Predicted SE =

Empiric Ideal SE − [(Suggested IOL − Empiric ideal IOL) × 0.50]

Using this equation in combination with the previous example, if the Hoffer Q formula suggested a −8.0 D IOL, we would calculate that based on the IOL actually implanted, a −8.0 D IOL would have produced a postoperative SE of +1.0 D.

The data were analyzed and tabulated separately for eyes in which a minus- or plus-power IOL was needed to achieve the empiric ideal SE. Correlation coefficients comparing the empiric ideal SE and the postoperative predictive SE were obtained for each formula (including the surgeon's choice or "actual" postoperative SE).

Back calculations of axial lengths in patients receiving minus-power IOLs were performed using the Holladay IOL Consultant software.

Results

Fifty patients had cataract extraction and IOL implantation. The preoperative SE was −18.51 D ± 4.97 (SD) and the mean axial length, 30.82 ± 2.02 mm. There were 26 plus IOLs and 24 minus IOLs implanted. Mean postoperative SE was −0.40 ± 0.95 D.

Tables 1 and 2 show the patient data of cases in which plus-power and minus-power IOLs, respectively, were implanted. The tables are ordered by the axial
T4 length measurements. Tables 3 and 4 show the range of deviation of each formula's calculated IOL power from the actual IOL power in the plus-power and minus-power groups, respectively.

Correlation coefficients comparing the empiric ideal SE to the actual and to the postoperative predicted SE were similar in each group. For the plus lenses, the correlation coefficients were as follows: actual—0.19; SRK/T—0.24; Hoffer Q—0.18; Holladay 1—0.17; and Holladay 2—0.18. For the minus lenses, they were as follows: actual—0.11; SRK/T—0.19; Hoffer Q—0.15; Holladay 1—0.14; and Holladay 2—0.11. The correlation coefficients comparing the actual postoperative SE to the postoperative predicted SE was greater than 0.92 for each of the formulas.

Back calculations in patients requiring minus-power IOLs revealed that in 75% of cases, calculations using shorter axial lengths would have produced the empiric ideal IOL as the recommended IOL. The mean difference between these "back calculated" axial lengths and the measured axial lengths used in our calculations was 0.67 ± 1.60 mm.

Discussion

It has been suggested that IOL calculation formulas work best for eyes with normal axial lengths.[1–7] In the present study, we examined the predictive capacity of 3 third-generation and 1 fourth-generation IOL calculation formulas in determining IOL power in eyes greater than 27.00 mm in axial length.

While the 4 formulas performed similarly for postoperative predicted SE, their predictive capacity appeared best in eyes in which a low-plus-power IOL was implanted; a lower percentage of undercorrections and overcorrections were seen in these eyes. Had the suggested IOL been implanted, the postoperative SE would have been between ±1.00 D in 92% of eyes with the SRK/T formula and 88% with the Hoffer Q, Holladay 1, and Holladay 2 formulas in the case of the plus-power IOLs; and in 54% with the SRK/T and Hoffer Q formulas, 63% with the Holladay 1 formula, and 41% with the Holladay 2 formula in the case of minus-power IOLs.

The actual postoperative SE was between ±1.00 D in 88% of cases with plus-power IOLs, which is similar to the predicted results of the 4 formulas. In cases with minus-power IOLs, the surgeon performed somewhat better than the lens formulas, achieving a postoperative SE between ±1.00 D in 77% of eyes. This difference was not statistically significant, however, as the correlation coefficients comparing the actual postoperative SEs to the postoperative predicted SEs approached 1.00 for each formula.

The improved predictive capacity in eyes in which plus lenses were implanted is probably related to the improved accuracy of axial length measurements in these shorter eyes. The mean axial length was 29.32 ± 1.37 mm in patients receiving plus IOLs and 32.20 ± 1.46 mm in those receiving minus IOLs.

The difficulties in IOL power calculations for longer eyes may be partly due to the anatomy of the

Table 1. Data of patients with plus-power IOLs.

Patient	Axial Length (mm)	Implanted IOL (D)	SRK/T Predicted (D)	Holladay 1 Predicted (D)	Hoffer Q Predicted (D)	Holladay 2 Predicted (D)	BCVA		Postop SE (D)
							Preop	Postop	
1	27.31	6.0	5.20	4.20	3.70	6.0	20/30	20/30	0.00
2	27.68	6.0	5.20	4.09	3.63	5.0	20/50	20/25	0.00
3	27.70	2.0	1.70	2.30	1.70	3.0	20/40	20/50	1.88
4	28.04	4.0	3.07	2.21	1.74	3.0	20/50	20/25	−0.50
5	28.24	4.0	3.18	2.24	1.78	3.0	20/30	20/30	−0.50
6	28.40	6.0	7.40	6.70	6.20	6.0	20/40	20/20	0.00
7	28.51	6.0	5.60	4.80	4.30	5.0	20/40	20/25	0.00
8	28.64	5.0	4.80	3.90	3.60	5.0	20/60	20/30	0.25
9	29.17	4.0	3.70	2.60	2.40	4.0	20/25	20/20	−0.13
10	29.21	3.0	1.70	1.00	0.60	2.0	20/60	20/30	0.50
11	29.35	3.0	2.10	1.50	1.10	2.0	20/800	CF	0.00
12	29.38	5.0	4.75	4.03	3.95	5.0	20/400	20/200	−1.00
13	29.38	3.0	3.00	2.30	1.80	3.0	20/200	20/25	0.00
14	29.56	3.0	3.09	2.31	1.98	3.0	LP	20/400	−0.50
15	29.60	5.0	4.38	3.67	3.57	5.0	20/40	20/25	−0.50
16	29.70	3.0	2.10	1.50	1.00	2.0	20/40	20/30	0.00
17	29.77	3.0	2.70	2.10	1.70	3.0	20/50	20/40	−0.63
18	29.90	1.0	1.10	0.53	0.10	1.0	20/100	20/60	−0.38
19	29.95	1.0	1.20	0.60	0.20	1.0	20/50	20/40	0.00
20	30.43	2.0	1.88	1.28	0.95	2.0	20/70	20/25	0.00
21	30.45	2.0	1.61	1.02	0.61	2.0	20/400	20/50	−1.75
22	30.68	3.0	2.42	1.81	1.56	3.0	20/200	20/60	−0.63
23	31.10	2.0	1.91	1.33	1.03	2.0	20/80	20/40	0.00
24	31.45	2.0	2.11	1.48	1.21	2.0	20/200	20/100	−1.25
25	31.94	1.0	1.04	0.50	0.13	1.0	20/80	20/40	−0.50
26	32.13	1.0	0.64	0.14	−0.29	1.0	20/40	20/25	0.00

BCVA = best corrected visual acuity; SE = spherical equivalent; LP = light perception; CF = finger counting

posterior pole. The fovea is approximately 4.5 mm (3 disc diameters or 15 degrees) from the center of the optic nerve. Holladay and others (personal communication) have performed high-resolution B-scans with the Innovative Imaging System using horizontal sections through the optic nerve and measuring the distance from the corneal vertex to a point 4.5 mm temporal to the center of the optic nerve. In eyes with axial lengths longer than 30.0 mm, a posterior pole staphyloma temporal to the fovea was common and the corneal vertex–fovea distance was approximately 0.5 to 1.5 mm shorter than the distance from the corneal vertex to the bottom of the staphyloma, which is where the A-scan usually finds the perpendicular axis and records the axial length.[11]

When we performed back calculations, we found that, in most cases, using the back-calculated (shorter) axial length could have improved our ability to predict emmetropia. As the power calculations for cases requiring minus-power IOLs tended to suggest IOLs of higher minus power than the empiric ideal IOLs, it is clear that by using shorter axial lengths, the results would empirically improve.

To illustrate this point, we recently performed diagnostic B-scan ultrasonography on selected patients who had preoperative evaluation subsequent to this study. As

Table 2. Data of patients with minus-power IOLs.

Patient	Axial Length (mm)	Implanted IOL (D)	SRK-T Predicted (D)	Holladay 1 Predicted (D)	Hoffer Q Predicted (D)	Holladay 2 Predicted (D)	BCVA		Postop SE (D)
							Preop	Postop	
1	27.16	−1.0	−3.39	−3.34	−3.81	3.0	CF	20/60	−2.00
2	29.94	−2.0		−5.50		−7.0	20/150	20/70	0.25
3	30.54	−1.0	−2.20	−2.30	−2.96	−2.0	20/40	20/25	−0.50
4	30.60	−1.0	0.10	−0.40	−0.80	−2.0	20/100	20/30	0.00
5	30.61	0.0	−1.59	−1.83	−2.46	−2.0	20/50	20/40	1.25
6	30.61	−5.0	−12.75	−10.99	−11.96	−12.0	20/100	20/80	−1.50
7	30.72	−1.0	0.70	0.20	−0.20	1.0	20/50	20/20	−0.50
8	31.30	−2.0	−2.40	−4.10	−4.60	−4.0	20/100	20/40	−0.50
9	31.30	−3.0	−4.70	−7.10	−7.30	−8.0	20/100	20/40	−0.25
10	31.83	−3.0	−5.31	−4.79	−5.65	−5.0	20/100	20/40	0.50
11	31.89	−6.0	−8.34	−7.00	−7.95	−6.0	20/200	20/40	−0.63
12	31.95	−1.0	−2.00	−2.20	−2.70	−2.0	20/60	20/30	−1.00
13	32.12	−2.0	−2.30	−2.50	−3.00	−3.0	20/80	20/60	0.13
14	32.13	−2.0	−3.40	−3.50	−3.90	−3.0	20/60	20/30	−1.88
15	32.16	−2.0	−0.90	−1.30	−1.80	−2.0	20/40	20/50	1.50
16	32.44	−1.0	−3.14	−3.27	−3.69	−3.0	20/200	20/40	−2.75
17	32.44	−5.0	−9.26	−7.69	−8.70	−8.0	20/80	20/30	−0.38
18	32.81	−4.0	−6.90	−6.10	−7.10	−7.0	20/100	20/20	0.25
19	33.17	−2.0	−3.00	−3.20	−3.70	−3.0	20/80	20/40	−0.38
20	33.41	−4.0	−5.40	−5.30	−5.90	−6.0	20/150	20/100	−0.25
21	33.50	−3.0	−7.87	−7.02	−8.09	−8.0	20/400	20/200	−1.00
22	33.99	−2.0	−3.09	−3.32	−4.12	−3.0	20/40	20/20	−0.38
23	34.50	−3.0	−6.20	−6.00	−6.50	−7.0	20/70	20/60	−3.88
24	34.66	−4.0	−9.10	−7.90	−8.30	−10.0	20/50	20/30	−0.50

BCVA = best corrected visual acuity; SE = spherical equivalent; CF = finger counting

Table 3. Deviation of calculated IOL power from empiric ideal IOL power in eyes with plus-power IOLs (n = 26).

Formula	Diopters of IOL Power (%)						
	≥−3	−2	−1	0	+1	+2	≥+3
Actual IOL implanted	8	0	8	50	27	8	0
SRK/T	4	4	8	38	27	15	4
Hoffer Q	8	19	31	27	12	4	0
Holladay 1	8	4	23	38	19	8	0
Holladay 2	8	8	23	38	15	8	0

Holladay suggested, an obvious posterior pole staphyloma was found temporal to the optic nerve and macula in many eyes with axial lengths longer than 30.0 mm (Figure 1). However, not all such patients have a staphyloma (Figure 2). Performing B-scans, prospectively, in all eyes with axial lengths longer than 27.0 mm will be the basis of our next *study*.

In lieu of these findings, we now perform preoperative B-scans in all eyes longer than 27.0 mm having IOL implantation, and we use an adjusted axial length in

Table 4. Deviation of calculated IOL power from empiric ideal IOL power in eyes with minus-power IOLS (n = 24).

	Diopters of IOL Power (%)						
Formula	**≥−3**	**−2**	**−1**	**0**	**+1**	**+2**	**≥+3**
Actual IOL implanted	0	4	13	29	25	4	25
SRK/T	21	8	25	4	8	17	17
Hoffer Q	29	8	21	4	17	13	8
Holladay 1	13	17	25	8	8	13	17
Holladay 2	29	8	21	8	8	4	21

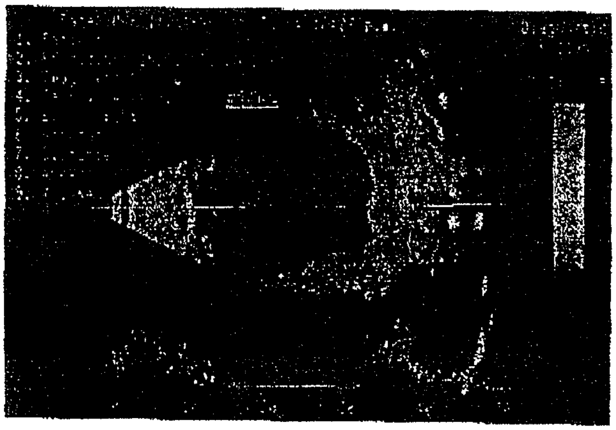

Figure 1. (Zaldivar) B-scan of patient with posterior pole staphyloma: The horizontal section through the optic nerve illustrates the presence of a posterior pole staphyloma temporal to the optic nerve and macula in a patient with an axial length longer than 30.0 mm.

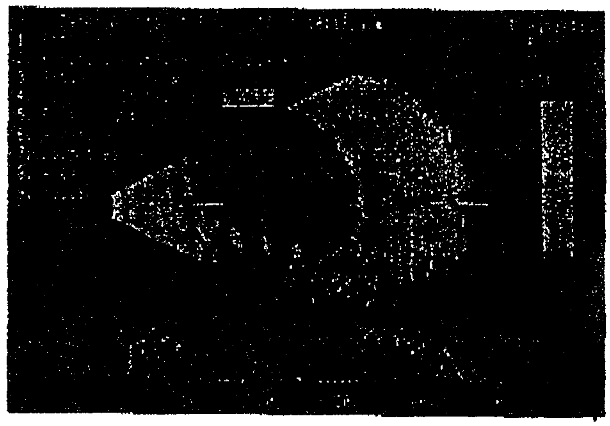

Figure 2. (Zaldivar) B-scan of patient without posterior pole staphyloma: The horizontal section through the optic nerve demonstrates the absence of a staphyloma in a patient with an axial length longer than 30.0 mm.

our power calculations in patients with a posterior pole staphyloma. While standard B-scan ultrasonography can help identify a posterior pole staphyloma, we have been unable to consistently locate the center of the fovea using our current B-scan unit. Therefore, the problem of identifying the appropriate site of axial length measurement remains unsolved.

The observed IOL power calculation errors are probably the result of difficulties in measuring the appropriate axial length of longer eyes. However, we must still consider other potential sources of error: differences in IOL design between the low plus-power and low minus-power Domilens SiFlex 1 and inherent errors in the IOL calculation formulas that become more problematic in eyes with longer axial lengths.

Conclusion

In eyes with axial lengths longer than 27.0 mm having cataract extraction with IOL implantation, current third- and fourth-generation lens calculation formulas have a tendency to over minus patients between −1.0 and −4.0 D, leaving patients with postoperative hyperopia. The performance of these formulas appears better for plus-power IOL implantation than for minus-power IOL implantation, which is related to the higher incidence of posterior pole staphyloma in eyes with axial lengths longer than 30.0 mm. The use of B-scan ultrasonography to identify the location of a posterior pole staphyloma, along with refinements in preoperative measurement techniques and equipment, lens calculation formulas, and IOL design, may help improve the accuracy of IOL calculations in eyes with extreme myopia.

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