

# Intraocular Lens Power Calculation After Laser In Situ Keratomileusis for Myopia and Hyperopia

## A Standardized Approach

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**Purpose.** (1) To determine the effect of myopic and hyperopic laser in situ keratomileusis (LASIK) on calculation of intraocular lens (IOL) power. (2) To determine a standard way to approach the IOL power determination after LASIK, and (3) To compare different suggested methods. **Methods.** Biometric analysis and theoretical calculation of IOL powers for eyes undergoing LASIK for myopia and hyperopia were performed. **Results.** Manual keratometry after LASIK for myopia resulted in underestimation of IOL power. Manual keratometry after hyperopic LASIK resulted in overestimation of IOL power. The amount of error was directly related to the amount of correction by LASIK. **Conclusion.** The pre-LASIK refraction can be used theoretically to determine an accurate IOL power.

**Key Words:** LASIK—Myopia—Hyperopia—Cataract—Intraocular lens—Power calculation

Excimer laser keratectomy, especially laser in situ keratomileusis (LASIK), for correction of refractive errors has gained increasing popularity among patients and ophthalmologists in the last few years. It is estimated that in the year 2000 the number of refractive surgical procedures in the United States exceeded 1.5 million.<sup>1</sup> In the next several decades, many of these LASIK patients will develop visually significant senescent cataracts and will need cataract extraction. Performing cataract extraction in a post-refractive surgery presents no extraordinary technical difficulty. However, calculation of intraocular lens (IOL) power to achieve emmetropia appears to be a more significant challenge.

Limited experience with IOL calculation in eyes after photorefractive keratectomy (PRK) and LASIK for myopia using currently available formulas has indicated a trend toward underesti-

mation of IOL power and resultant hyperopia after IOL implantation.<sup>2-4</sup> To our knowledge, no large series of IOL calculation after LASIK for hyperopia has been reported. Because refractive surgery patients understandably have high expectations for uncorrected visual acuity, post cataract extraction hyperopia would be especially bothersome to them. Accordingly, more precise methods for calculation of IOL power after corneal refractive surgery need to be developed. Suggested ways to improve the accuracy of IOL power calculations include use of theoretical formulas (SRK-T, Hoffer Q), hard contact lens refraction, and use of a corneal power.<sup>5</sup>

The current study was designed to determine the effect of corneal excimer refractive surgery on the IOL power measurement and to develop a logical approach to calculating more accurate IOL powers.

## MATERIALS AND METHODS

This study was approved by the Institutional Review Board at the University of California, Davis. Informed consent was obtained from all patients whose data were used in this study. Nineteen eyes of 10 patients after myopic LASIK and eight eyes of four patients after hyperopic LASIK were randomly selected for this analysis. The range of change in spherical equivalent for myopic LASIK was from -0.6 to -9.88 D. For hyperopic LASIK the range was from +0.75 to +6.00D. The axial lengths ranged from 22.78 mm to 28.46 mm (average 24.97 mm, standard deviation (SD) 1.59 mm) for myopes and from 21.62 mm to 22.9 mm (average 22.89 mm, SD 1.065 mm) for hyperopes.

All patients had a complete ophthalmic examination, including manual keratometry, manifest and cycloplegic refraction, and dilated funduscopic examination. For the purpose of the study, axial lengths were measured with a Humphrey ultrasound unit. (Allergan Humphrey, San Leandro, CA, U.S.A.). A drop of local anesthetic (proparacaine) was instilled in the eye, and a contact ultrasound probe was placed on the cornea to determine axial length. The measurements were repeated five times, and if any measurement deviated by more than 0.3 mm from the other values, the measurement was repeated until the all values were within 0.3 mm of one another. The average of five measurements was used for

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IOL calculation. All patients underwent uncomplicated LASIK by one of the three surgeons (MJM, FGF, VF). The Hansatome microkeratome (Bausch & Lomb Pharm Inc., Claremont, CA, U.S.A.) was used to create either an 8.5-mm flap for myopic patients or a 9.5-mm flap for hyperopic patients. Flap thickness was set either at 160 or 180  $\mu\text{m}$ . The hinge was superior in all patients. Stromal photoablation was performed using the VISX Star II system (VISX, Inc., Santa Clara, CA, U.S.A.). All patients were placed on Tobradex (Alcon Laboratories, Inc., Fort Worth, TX, U.S.A.) drops four times daily starting the first day after LASIK for a period of 5 days. Patients were examined 1 week, 1 month, and 3 months after the operation. Manual keratometry, corneal topography, and refraction were performed at each visit. Pre- and post-LASIK keratometry readings were used to determine an IOL power using the SRK-T formula to achieve emmetropia. The theoretical assumption was that the patient would receive an Acrylic MA-60 foldable IOL (Alcon Laboratories, Inc., Fort Worth, TX, U.S.A.; A constant 118.9) or a silicone SI40 (Storz, Inc., St. Louis, MO, U.S.A.; A constant 118). The IOL power to achieve emmetropia was calculated using each of the following three methods for all patients:

#### Method I

We used the manual keratometry values after LASIK. The SRK-T formula was used to calculate IOL Power.

#### Method II

As described by Holladay<sup>7</sup> and Guyton et al.,<sup>8</sup> a refractive corneal power was determined. The change in spherical equivalent and pre-LASIK keratometry readings were used to determine corneal power. For myopic LASIK, the change in spherical equivalent at the spectacle plane was subtracted from the pre-LASIK average keratometry values. For hyperopic LASIK, the change in spherical equivalent was added to the pre-LASIK average keratometry readings. These derived corneal powers were then used in the SRK-T formula to determine the IOL power.

#### Method III

We determined an IOL power for emmetropia before LASIK as if the patient had had no corneal refractive procedure. Using this theoretical IOL power before LASIK and the change in spherical equivalent, an IOL power was predicted. The following assumptions were made:

1. To achieve emmetropia, the change in spherical equivalent induced by LASIK has to be balanced by the change in IOL power.
2. For every diopter (D) of change in IOL power, only 0.7 D of change in refraction at the spectacle level will be achieved.<sup>9</sup> This is due to position of the IOL behind the iris as opposed to the spectacle plane with a vertex distance of 12–13 mm.<sup>8</sup> The results of these three approaches were compared. Because the data in this study included eyes from the same patients, and theoretically there could be a correlation between the right and left eye of the same patient, a bivariate analysis was performed. To determine whether there is a statistically significant difference between methods I and III, Hotelling's  $T^2$  test was performed to the bivariate differences between methods I and III.

To explore the relationship between the refractive change induced by LASIK and the error in IOL power determination, a linear regression analysis was performed for the 10 myopic patients (total of 19 eyes) and four hyperopic patients (total of eight eyes). The best-fit curve was found and used to develop a theoretical nomogram to determine the expected deviation in IOL power after LASIK. The statistical significance of the linear regression analysis was determined by the degree of correlation as indicated by  $p$  values.

### CASE EXAMPLE

A 48-year-old male presented to UC Davis Medical Center with a visually significant posterior subcapsular cataract right eye. The patient had undergone uncomplicated bilateral simultaneous LASIK for correction of myopia 1 year before presentation. Pre- and post-LASIK data follow:

Pre-LASIK refraction: -5.25  
 Post-LASIK refraction before cataract IOL calculations: plano  
 Pre-LASIK keratometry: 45.60/46.70@27  
 Post-LASIK keratometry: 41.75/42.13@169  
 Axial length: 25.0 mm  
 IOL type: SI40, A-Constant 118

#### Method I

Using the keratometry readings after LASIK, and the axial length utilizing SRK-T formula, the IOL power for emmetropia is calculated: 16.80 D

#### Method II

A corneal power is calculated:

Average pre-LASIK keratometry: 46.15 D  
 Refraction derived Ks:  $46.15 - 5.25 = 40.90$  D  
 Using SRK-T formula, the IOL power for emmetropia would be: 18.29 D

#### Method III

IOL power using pre-LASIK values: 12.62 D

The change in IOL power after LASIK must balance the change in spherical equivalent, and because for every diopter of IOL change the refraction changes by only 0.7 D, the IOL power to achieve emmetropia after LASIK is:  $12.62 + (5.25/0.7) = 20.12$  D

This patient received a 20.0 D IOL and the postoperative refraction was:  $+0.50 + 0.25 \times 005$ . Methods I and II would have underestimated the IOL power.

### RESULTS

The IOL powers derived by each of the three approaches are shown in Table 1 and Figure 1. These findings seem to indicate that using manual keratometry readings after LASIK results in a lower IOL power than expected. Using corneal powers resulted in a higher IOL power, and using the change in spherical equivalent to predict the power (method III) resulted in an even higher IOL power. Statistical analysis comparing methods I and III showed this to be highly significant, with a mean difference of 2.3756

TABLE 1. IOL powers after myopic LASIK using three different methods

Patient	Eye	Change in SE* (diopters)	Pre-LASIK average Ks	Post-LASIK average Ks	Refractive K†	IOL power (post-LASIK Ks)	IOL power based on refractive Ks	Predicted IOL‡	%Difference§
A	OD	0.63	44.50	43.50	43.87	19.53	18.95	19.35	-0.92
B	OS	1.37	43.88	43.00	42.51	20.23	20.65	21.25	5.04
C	OS	1.75	46.13	44.00	44.38	22.69	22.73	23.43	3.26
B	OD	2.00	44.00	43.00	42.00	20.00	20.94	21.77	8.85
C	OS	2.13	46.13	44.50	44.00	22.53	22.67	23.28	3.23
I	OD	2.25	44.50	42.63	42.25	22.51	20.82	23.52	4.49
F	OD	3.38	43.25	40.31	39.87	20.41	20.76	21.79	6.76
F	OS	4.13	43.75	40.13	39.62	19.53	20.31	21.05	7.78
G	OD	4.25	43.00	39.88	38.75	20.96	21.84	22.98	9.63
G	OS	4.38	43.00	39.88	38.62	20.74	21.98	23.22	11.96
J	OD	4.88	45.13	41.50	40.25	15.84	17.26	18.85	19.00
A	OS	5.13	44.63	42.25	39.50	20.36	23.07	24.95	22.54
H	OD	6.00	46.25	41.38	40.25	18.37	19.49	21.17	15.24
E	OS	7.38	43.40	39.25	36.02	17.16	20.60	22.23	29.55
H	OS	7.63	46.13	40.63	38.50	18.83	21.03	22.92	21.72
E	OD	7.75	43.75	39.38	36.00	16.38	20.01	21.74	32.72
D	OS	8.75	44.75	38.88	36.00	12.49	15.83	16.50	32.11
D	OD	9.63	45.12	38.65	35.49	13.29	16.81	17.62	32.58
J	OS	9.88	45.35	39.00	31.47	16.62	20.50	22.00	32.37

\* Change in SE: Change in spherical equivalent induced by LASIK

† As described in methods: Refractive K = Pre-LASIK average keratometry—Change in spherical equivalent

‡ As described by method III

§  $[(\text{Method III} - \text{Method I}) / \text{Method I}] \times 100$

(standard error: 0.5738) for the right eyes and 3.1956 (standard error: 0.6039) for the left eyes. The  $p$  value was 0.0039.

The data also appear to indicate that using a refractive derived corneal power as described by Holladay<sup>7</sup> and Koch et al.<sup>8</sup> (method II) works well for eyes that have had lower degrees of myopia corrected by LASIK. After corneal ablation for higher degrees of myopia, however, this method gives lower IOL power estimation than method III and could potentially result in hyperopia after cataract extraction.

To explore the relationship between the amount of IOL underestimation and the change in refraction induced by LASIK for myopia, a linear regression model for repeated measurements was fitted for the 10 myopic patients (19 eyes). This model correlated the difference in IOL power using methods I and III against the change in spherical equivalent after LASIK. A direct linear relationship was noted. The results are shown in Figure 2. This correlation was statistically highly significant ( $p < 0.0001$ ). The best-fit equation indicates that using the manual keratometry after

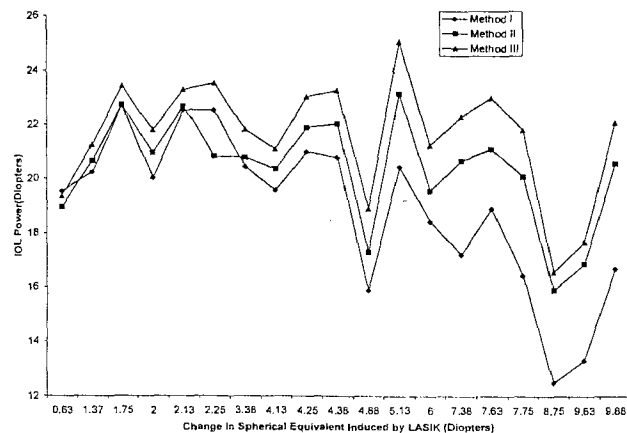


FIG. 1. Comparison of the IOL powers using different methods after myopic LASIK.

LASIK can theoretically result in a 3.8175% underestimation of IOL power for every diopter of change in refraction brought about by LASIK. This applied to both right and left eyes (standard error: 0.3103%)

A similar analysis was performed for our four patients (eight eyes) after hyperopic LASIK. The results are shown in Table 2 and Figure 3. These results indicate that using keratometry readings after hyperopic LASIK resulted in a higher IOL power than predicted. This would theoretically result in myopia after IOL inser-

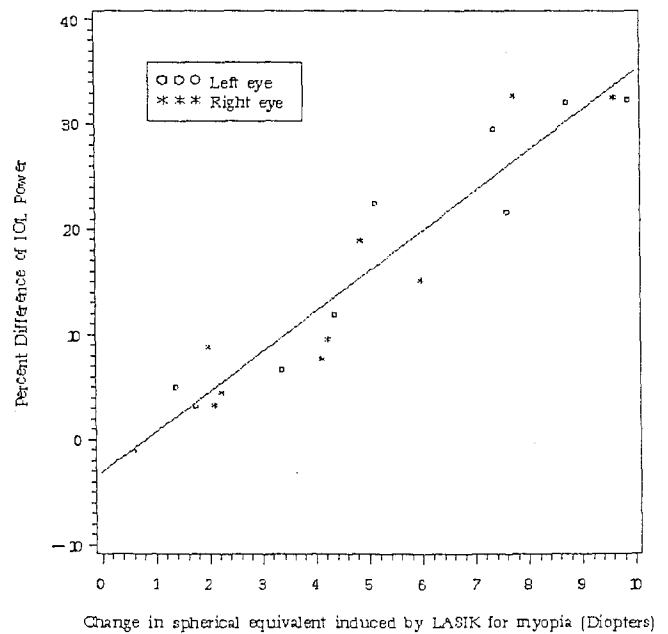


FIG. 2. Correlation of theoretical IOL power underestimation (percent underestimation) versus the change in spherical equivalent (diopters) induced by myopic LASIK.  $n = 10$  patients (19 eyes),  $p < 0.0001$ .

% difference =  $-3.084 + (3.819 \times \text{change in spherical equivalent})$ .

TABLE 2. IOL powers after hyperopic LASIK as determined by the three different approaches

Patient	Eye	Change in SE* (diopters)	Pre-LASIK average Ks	Post-LASIK average Ks	Refractive Ks†	IOL power post-LASIK Ks	IOL based on refractive Ks	Predicted IOL power	%Difference‡
K	OD	0.75	42.13	42.50	42.88	20.30	19.77	19.68	-3.05
K	OS	0.88	42.00	43.88	42.88	20.20	20.60	20.46	1.29
L	OS	1.38	41.50	43.25	42.88	23.42	23.67	23.31	-1.00
L	OD	3.63	42.75	45.75	46.38	25.02	24.21	22.93	-8.51
M	OS	4.13	42.75	46.00	46.88	25.06	23.29	22.51	-10.1
N	OD	4.75	44.38	48.50	49.13	16.10	15.35	12.68	-21.2
N	OS	5.25	44.75	48.75	50.00	22.16	20.74	18.82	-17.87
M	OD	6.00	45.00	50.25	51.00	18.76	17.91	14.19	-24.30

\* As induced by LASIK

† Pre-Lasik Average Ks + change in spherical equivalent

‡ [(Method III - Method I)/Method I]x100

tion. Using a corneal power appeared to decrease the amount of overestimation. However, again, after LASIK for higher degrees of hyperopia, this approach still overestimated the IOL power. The results of the linear regression analysis of the IOL power deviation (% difference = [(method I-method III)/method I] x100) against the change in spherical equivalent induced by LASIK are shown in Figure 4. Again we noted a direct statistically significant ( $p = 0.0054$ ) relationship between the percent difference of the IOL power and the change in spherical equivalent induced by LASIK. For every diopter of change in spherical equivalent made by LASIK, there is a theoretical overestimation of IOL power by 4.4294%, if manual keratometry (method I) is used as opposed to method III.

We performed a linear regression analysis on the dioptric difference between the predicted IOL power and the IOL power based on the post-LASIK keratometry. A best-fit equation for a straight line was obtained. These results are shown in Figures 5 and 6. The correlation was statistically significant ( $p < 0.0001$  for myopic LASIK,  $p = 0.012$  for hyperopic LASIK). Using these equations, we developed a theoretical reference nomogram (Tables 3, 4) to adjust the IOL power for emmetropia.

## DISCUSSION

Our results indicate that with the use of current theoretical formulas such as SRK-T, IOL power would theoretically be underestimated after myopic LASIK and overestimated after hyperopic

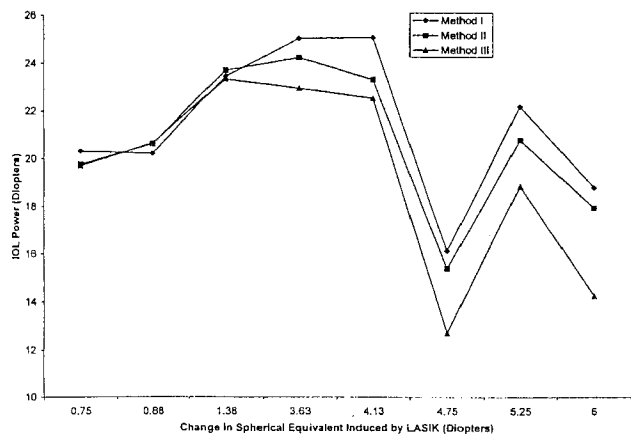


FIG. 3. Comparison of the IOL powers using different methods after hyperopic LASIK.

LASIK. The degree of error is directly related to the amount of refractive change induced by LASIK. Other investigators have found similar results after LASIK and PRK for myopia. Leshner et al.,<sup>10</sup> Kalski et al.,<sup>2</sup> and Seitz et al.<sup>5,6</sup> have reported hyperopia in eyes that had undergone cataract extraction after PRK, despite aiming for emmetropia. To our knowledge, no reported clinical experience with cataract extraction after hyperopic LASIK is currently in the literature. The source of error in IOL power after LASIK may lie in the inability to determine adequately the refractive power of the cornea. Manual keratometry measurements rely on the determination of a radius of curvature of the anterior surface of the cornea in the paracentral 3 mm of the cornea. The dioptric power of the cornea is then derived from the radius of curvature using an effective refractive index (e.g., 1.3375 for Javal Keratometer). Considering that the currently optical zones of 6–7 mm are routinely used in LASIK, the radius of curvature should be accurately measured by the current manual keratometry units. The refractive index is based on the model eye. In the Gullstrand model eye, a factitious lens with one refractive surface represents the

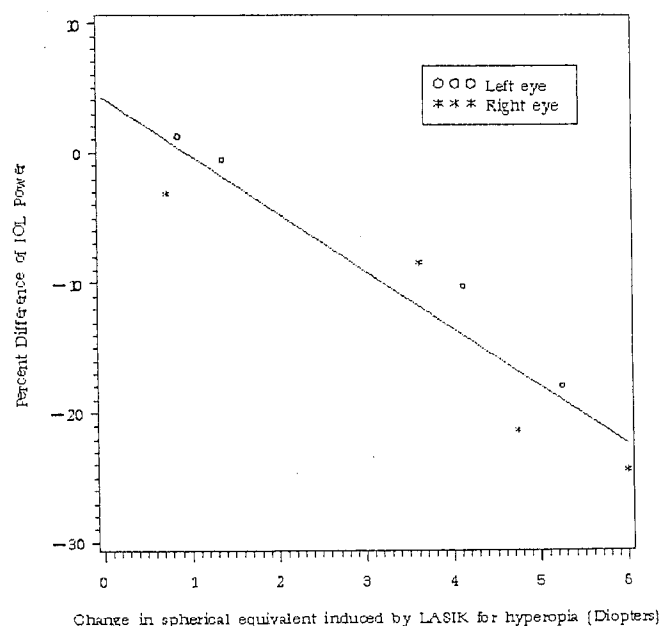


FIG. 4. Correlation of theoretical IOL power overestimation (percent overestimation) versus the change in spherical equivalent (diopters) induced by hyperopic LASIK.  $n = 8$  patients (4 eyes),  $p = 0.0054$ . % difference =  $4.289 - (4.429 \times \text{change in spherical equivalent})$ .

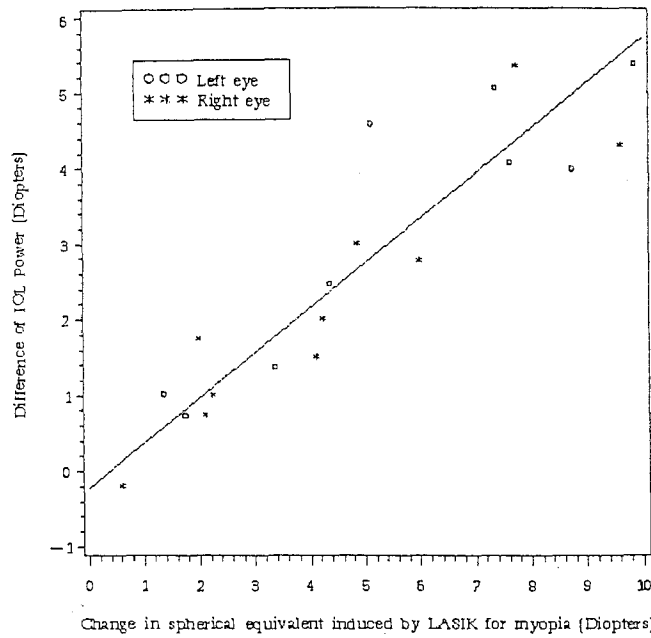


FIG. 5. Correlation of IOL power underestimation in diopters versus the change in spherical equivalent induced by myopic LASIK. n = 10 patients (19 eyes), p < 0.0001. Diopters of underestimation = -0.231 + (0.595, X change in spherical equivalent).

cornea that in reality has a posterior and an anterior refractive surface. When LASIK is performed, however, only the anterior curvature is changed. This results in a new refractive index that depends on how much tissue was ablated. Seitz and Langen-

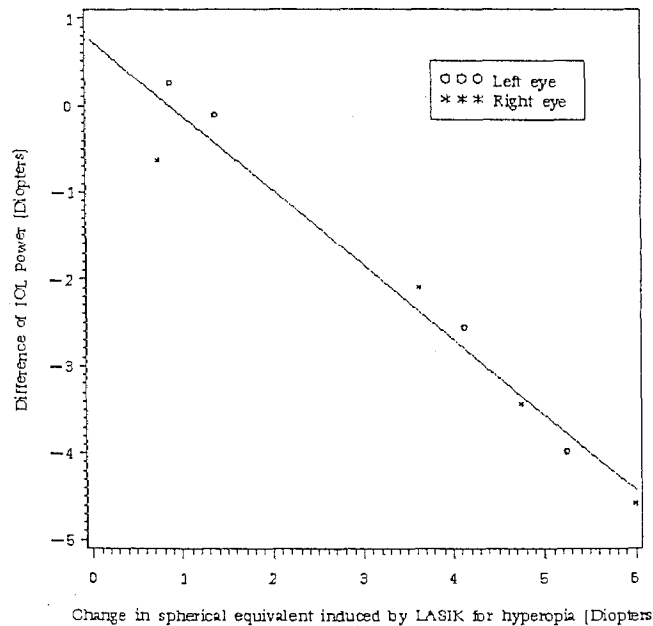


FIG. 6. Correlation of IOL power overestimation in diopters versus the change in spherical equivalent induced by hyperopic LASIK. n = 4 patients (8 eyes), p = 0.0012. Diopters of IOL overestimation = 0.751 - (0.862 X change in spherical equivalent).

TABLE 3. Nomogram of IOL power adjustment for emmetropia after myopic LASIK

Change in SE induced by LASIK (diopters)	Increase the IOL power (diopters)
1.00	0.36
2.00	0.96
3.00	1.55
4.00	2.15
5.00	2.74
6.00	3.34
7.00	3.93
8.00	4.53
9.00	5.12
10.00	5.72

bucher,<sup>6</sup> after compiling the results from the clinical experience of other investigators, noted a difference between true corneal power and the measured corneal power after PRK. The difference was directly related to the change in spherical equivalent. The same authors also demonstrated a linear relationship between ablation depth and the deviation of measured keratometric powers from true corneal refractive power.

Several authors have described methods for overcoming calculation errors. These include a hard contact lens method and refraction-derived corneal powers as suggested by Holladay<sup>7</sup> and Koch et al.<sup>8</sup> Both of these methods have their shortcomings. The contact lens method depends on obtaining an adequate refraction, which may not be possible in a patient with a visually significant cataract. Using the changes in spherical equivalent to estimate refractive K values of the cornea depends on having the pre-LASIK keratometry readings, which may not be readily available. We evaluated this method and found that, theoretically, it can determine IOL power accurately in eyes that have had LASIK for low degrees of refractive errors (<1.5 D). When higher degrees of corneal ablation are performed, this method still underestimates the IOL power after myopic LASIK and overestimates the IOL power after hyperopic LASIK. To evaluate this method, we used the refraction at the spectacle plane. If the refraction at the corneal plane were used instead, the error would be even higher. The source of error in this approach may be that it makes the assumption that there is a one-to-one relationship between change in refraction and the change in corneal dioptric power. Our approach does not make this assumption.

We also took into account that in the range of the axial lengths in our study, a unit of change in IOL power did not change the refraction at the spectacle plane by one unit. Our method, therefore, has the theoretical advantage of greater accuracy after LASIK for refractive errors of greater than 2 D. The primary disadvantage of both our approach and the approach of others is that some pre-LASIK values need to be available, and this may not always be

TABLE 4. Nomogram for IOL power adjustment for emmetropia after hyperopic LASIK

Change in SE induced by LASIK (diopters)	Decrease IOL power (diopters)
1.00	0.00
2.00	0.97
3.00	1.84
4.00	2.70
5.00	3.56
6.00	4.42

possible.<sup>7,8</sup> It may be easier to obtain the pre-LASIK refractive error than the pre-LASIK K values, because many patients keep their old glasses or contact lens prescriptions. We attempted to eliminate the need for pre-LASIK keratometry values by developing a formula to estimate the amount of error in IOL power using the change in refractive error. Using this formula, we then developed the nomograms presented in the Results section (Tables 3 and 4). The nomograms can be used in the following fashion: Faced with a patient who has undergone LASIK and needs cataract extraction, the clinician can proceed as normal and use the post-LASIK keratometry and axial length to determine an IOL power. This IOL power will then have to be adjusted. If the change in refraction induced by LASIK is known, the power of the IOL can be adjusted accordingly using the nomogram.

It must be noted that the correlations and the conclusions presented in this study are theoretical and need to be tested in a clinical series. The assumptions made, however, are logical. These conclusions are also based on our patient data set with a specified range of refractive errors (up to -10.00 D for myopic LASIK and + 6.00 D for hyperopic LASIK), axial lengths, and a specific posterior chamber IOL types. These recommendations may not, therefore, be applicable to eyes and refractive errors that fall outside the range of our data. Further clinical experience will be needed to test these recommendations. Our approach still has the weakness that it requires some pre-LASIK information. It is also based on a small sample size. An ideal approach would use a corrective nomogram that would eliminate the need for any pre-

LASIK data. Further clinical experience will be needed to test these recommendations.

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