Clinical and Theoretical Results of Intraocular Lens Power Calculation for Cataract Surgery After Photorefractive Keratectomy for Myopia

Monica T. P. Odenthal, MD; Cathrien A. Eggink, MD; Gerrit Melles, MD, PhD; Jan H. Pameyer, MD; Annette J. M. Geerards, MD; W. Houdijn Beekhuis, MD

Objectives: To describe the refractive results of cataract surgery after photorefractive keratectomy (PRK) for patients with myopia, and to find a more accurate method to predict intraocular lens (IOL) power in these cases.

Design: Nonrandomized, retrospective clinical study.

Patients and Methods: Nine patients (15 eyes) who underwent cataract surgery after prior PRK to correct myopia were identified. The medical records of both the laser and cataract surgery centers were reviewed.

Main Outcome Measures: Eight different keratometric values (K values; measured or calculated) were entered into 3 different IOL calculation formulas: SRK/T, Holladay 1, and Hoffer Q. The actual biometry and IOL parameters were used to predict postoperative refraction, which was compared with the actual refractive outcome. Also, the relative underestimation of the refractive change in corneal dioptic power by keratometry after PRK was calculated.

Results: In 7 of 15 eyes, IOL exchange or piggybacking was performed because of hyperopia. Retrospectively, the most accurate K value for IOL calculation was found to be the pre-PRK K value corrected by the spectacle plane change in refraction. Use of the Hoffer Q formula would have avoided postoperative hyperopia in more cases than the other formulas. The mean underestimation of the change in corneal power after PRK varied from 42% to 74%, depending on the method of calculation.

Conclusion: The predictability of IOL calculation for cataract surgery after PRK can be improved by using a corrected, refraction-derived K value instead of the measured, preoperative K value.

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EXCIMER LASER photorefractive keratectomy (PRK) is widely used as a safe and predictable method to correct myopia. With time, an increasing number of patients with cataract will have undergone PRK or another method of corneal refractive surgery (eg, laser-assisted in situ keratomileusis [LASIK]).

Intraocular lens (IOL) power calculated after corneal refractive surgery may be inaccurate and can lead to postoperative refractive surprises. Inaccurate postoperative refractions have been reported in eyes that have undergone cataract extraction after radial keratotomy, PRK, and LASIK. Recently, a number of theoretical studies that explain the causes of this problem and suggest ways to solve it have been published. However, clinical data on the actual outcomes of different methods of IOL calculation to improve the outcome of cataract surgery after previous refractive surgery are largely lacking; only case histories and small series of patients have been published thus far.

We analyzed 9 patients (15 eyes) who underwent cataract extraction after PRK surgery to correct myopia. Retrospectively, 8 different methods of measuring or calculating corneal keratometric values (K values) and 3 different standard IOL calculation formulas were used to calculate the difference between the expected refraction and the actual refraction after cataract extraction and IOL implantation.

CLINICAL RESULTS

We identified a group of 9 patients (15 eyes) who underwent PRK to correct myopia, followed by cataract extraction and implantation of an IOL. Table 1 shows...
PATIENTS AND METHODS

PATIENTS AND CLINICAL DATA

All members of the Dutch Association for Refractive Surgeons were asked to provide data from patients who had undergone PRK to correct myopia, followed by cataract extraction and implantation of an IOL. The medical records from the laser surgery center and the cataract surgery center were reviewed for all patients. All patients had previously provided written, informed consent, which included assenting to the use of medical information for scientific purposes if their identities were protected.

The following data were collected, if available: best-corrected visual acuity, subjective refraction, keratometer readings, and topographic values. These data were acquired from preoperative and postoperative (1-year follow-up) examinations concerning PRK and before and after cataract extraction.

The following IOL calculation data were acquired: the axial length, the formula or method used for IOL calculation or estimation by the cataract surgeon, the K value used in the formula, and the method of measuring or calculating the K value. Also, the A constant of the IOL, provided by the manufacturer for placement in the bag or the sulcus, the dioptric power of the IOL, and the position of the IOL in the eye (in the bag or the ciliary sulcus) were noted. These parameters were also acquired for the second IOL, in case an exchange took place.

METHODS

To calculate predicted refractive outcomes and compare them with the actual clinical data, 8 different methods of measuring or calculating the K value after refractive surgery by PRK were used (Figure 1). These measured or calculated values (were entered into each of 3 formulas, together with the lenspower and the A constant of the used IOL and the axial length, SRK/T, Holladay 1, and Hoffer Q) to obtain a prediction of refractive outcome in each case. A commercially available computer program was used to perform these calculations (Hoffer Programs; EyeLab Inc, Santa Monica, Calif).

The difference between the predicted refraction and the actual postoperative refraction gives an indication of the error in refraction (hyperopic, if positive; myopic, if negative), when each of the 24 specific combinations of the used K value and formula would have been used. This difference was calculated for each eye, K value, and formula and averaged for all eyes to compare the accuracy of the different K values in each formula.

When the achieved refraction, the axial length, the power, and the A constant of the IOL are all known variables after cataract extraction and IOL calculation, the only missing parameter in the equation is the K value. This theoretical K value (K-exact), reflects the “real” refractive power of the cornea and produces the power of the implanted IOL to achieve the actual refractive outcome when entered in the IOL calculation formula.

K-exact was calculated for each eye, with each of the 3 IOL calculation formulas, by repeatedly entering K values into the computer program for each formula until the entered K value predicted the actual postoperative refraction using the implanted IOL (Figure 2). Subtraction of K-exact from the average K value measured before PRK (K[prePRK]) produces the exact (calculated) keratometric change induced by PRK, ΔK(calc). This value may be compared with the measured keratometric change (ΔK[meas] = K[prePRK] − K[preCat]). The factor F-exact (ΔK[calc] / ΔK[meas]) measures the relative underestimation of the actual change in corneal curvature, measured by keratometry. Because this factor was calculated for the 3 IOL calculation formulas, we obtained 3 calculated factors, 1 for each formula: F-exact(SRK), F-exact(Holladay), and F-exact(Hoffer).

Another method for calculating the underestimation of keratometric change due to PRK is to divide the achieved subjective refractive change at the corneal plane (ΔSE[corn]) by the measured change (ΔK[meas]). Theoretically, this value should be 1.114 (or 11.4%) because only the front surface of the cornea is changed by PRK, and regular keratometry and topography use a keratometric index of 1.3375 for front and back curvature of the cornea combined, instead of the refractive index of the front corneal surface, air to corneal stroma, which is 1.37615. We define this factor (F-index) as ΔSE[corn] / ΔK[meas].

The patients ranged in age from 29 to 66 years (mean age, 49.8 years) at the time of PRK. The mean±SD preoperative spherical equivalent (SE) of the subjective refraction was −8.2±1.9 diopters (D) (range, −6 D to −12 D). The intended correction by PRK ranged from 6 D to 10 D (mean, 8.2 D). The exact intended correction of 1 patient (patient 6) who underwent PRK in another country was unknown. In 2 eyes, an enhancement procedure was performed to correct residual myopia by retreatment with PRK. Follow-up data from 1 year after refractive surgery or retreatment was available in 13 eyes; patient 7 did not return for the 1-year follow-up visit, and patient 2 had cataract surgery 5 months after PRK. For patient 2, we used measurements from this last PRK follow-up visit for calculations.

The mean interval between PRK (or retreatment, in 2 eyes) and cataract extraction was 2 years 9 months (range, 5 months to 5 years 4 months). All 15 eyes showed nuclear cataract, and 6 eyes also showed cortical or posterior subcapsular opacities.

Table 2 presents the preoperative and postoperative data concerning cataract extraction and IOL implantation for all 15 eyes. Seven different ophthalmologists performed the operations. Each cataract surgeon used the standard biometric measurements and IOL calculation formula of that specific cataract surgery center. Therefore, several formulas were used (not shown). In 14 eyes, the cataract extraction was performed by phacoemulsification; in 1 eye, a manual extracapsular cataract extraction technique was used. No intraoperative or postoperative complications, such as a ruptured capsule, vitreous loss, or endophthalmitis, occurred.

In 6 eyes, the K value measured before cataract extraction and after PRK, K(preCat), was used to calculate the power of the IOL before cataract surgery (conven-
determine the power of the IOL. An estimation of IOL and, in 1 eye, a second IOL was added (piggyback). D; SE). In 4 of these 6 eyes, exchange of the IOL took place, 
erative refraction ranging from +1 D to +6 D (mean, +3.3 
tional method). These 6 eyes achieved hyperopic postop-
Figure 1. Eight methods of measuring or calculating the keratometric (K) 
In the other 9 eyes, different methods were used to 
the IOL power by rule of thumb (“standard IOL method”) was 
In 2 eyes, a K value was estimated, using different 
In 2 eyes, automated refraction was performed during 
In 2 eyes, intraoperative exchange of the IOL took 
In the remaining 3 eyes, calculation or estimation of the power of the IOL was based on the refractive outcome in the contralateral eye.
The IOL exchange was performed intraoperatively in 2 eyes. In the other 5 eyes in which IOL exchange was performed or an IOL was added, the power of the second IOL was estimated using the original IOL power and the residual subjective refractive error. In these eyes, the interval between cataract surgery and subsequent surgery varied from 2 to 8 months (mean, 6 months). In 3 eyes, the IOL was again placed in the capsular bag: in 1 eye, in the ciliary sulcus and, in 1 eye, a second IOL was placed in the ciliary sulcus (piggyback). Twelve (80%) of 15 eyes achieved a final postop-
erative refraction (SE) within 1 D of emmetropia, including 
Twelve (80%) of 15 eyes achieved a final postoperative refraction (SE) within 1 D of emmetropia, including 7 eyes after IOL exchange or adding an IOL. The remaining 3 eyes achieved a final SE of –1.25 D or –1.5 D. In all eyes in which cataract surgery was performed after (often elaborate) discussions and calculations or reasoned estimation of the appropriate K value, an acceptable postoperative refraction was reached without the need for IOL exchange. No late postoperative complications, such as regression, corneal haze formation, instability of refraction, or other problems, were noted, apart from posterior capsule opacification.

THEORETICAL RESULTS

Table 3 presents the calculations of the difference between the actual (achieved, subjective manifest) refraction (SE) and the calculated expected refraction (SE). The calculated expected refraction was computed using the 3 IOL calculation formulas and 8 ways of measuring and calculating the K value for each eye. For each calculation, a number of eyes had to be excluded because keratometric values, corneal topography, and/or refraction data were incomplete. For patient 9, the right eye was excluded because of the addition (piggybacking) of another lens instead of IOL exchange, which made retrospective calculations using the power of the implanted IOL impossible. In 3 patients (4 eyes), the refractive change measured 1 year after PRK could not reliably be used to calculate a corrected K value. This was caused by a decline in visual acuity due to cataract and/or a myopic change in refraction due to nuclear sclerosis (patient 2, left eye; patient 3, both eyes; and patient 4, right eye).

A positive mean calculated difference between achieved and predicted refraction indicates that the actual refraction was more hyperopic than was predicted (Table 3). For example, for regular keratometer readings after PRK combined with the SRK/T formula, the mean ± SD achieved refraction in 13 eyes is 2.8 D ± 2.0 D more hyperopic than this combination of K value and IOL formula predicts. All 3 keratometric measurements based on actual preoperative measurements (K(preCat), SimK(preCat), and MinK(preCat)) before cataract extraction and after PRK yield a considerable positive mean difference with a wide range. This is consistent with our clinical finding of unexpected hyperopia after “conventional” keratometric measurements and IOL calculation (Table 2). Keratometric readings taken before PRK and corrected by the
change in refraction after PRK (K\textsubscript{prePRK} – ΔSE\textsubscript{spec}), K\textsubscript{prePRK} – ΔSE\textsubscript{corn}, SimK\textsubscript{prePRK} – ΔSE\textsubscript{spec}, and SimK\textsubscript{prePRK} – ΔSE\textsubscript{corn}) yield more accurate findings. The K values in this series of eyes that predict the actual achieved refraction most accurately are the values derived by correcting the K values measured before PRK, either manual or automated, with the change in refraction at the spectacle plane (K\textsubscript{prePRK} – ΔSE\textsubscript{spec}). Also, the range in the difference between actual and expected refraction is smaller when refractive change–corrected original keratometer readings are used instead of uncorrected keratometric or topographic measurements after PRK or instead of the measured keratometric change corrected by the theoretical factor of 1.114.

Table 4 shows the number and percentage of eyes with an achieved refraction after cataract surgery within 1 D of predicted refraction for the actual implanted IOL, using the 8 keratometric methods and 3 different IOL calculation formulas. From Table 4, we conclude that the IOL calculation is less predictable after PRK than in the normal situation, even after correcting the K value, because the maximal percentage is only 70%. Using uncorrected keratometric or topographic values (K\textsubscript{preCat}, SimK\textsubscript{prePRK}, or MinK\textsubscript{preCat}) will result in a high percentage of cases with a postoperative refractive error of more than 1 D. Using K\textsubscript{prePRK} – ΔSE\textsubscript{spec} in any of the 3 formulas resulted in the highest percentage of eyes within 1 D of the predicted refraction. A clear preference for one IOL calculation formula cannot be made from this table.

Table 5 shows the number and percentage of eyes with an achieved refraction less than 0.5 D more hyperopic than was predicted, using different keratometric values and IOL calculation formulas. We can retrospectively conclude that use of the Hoffer Q formula, combined with a K value derived from the original K value minus the refractive change due to PRK (K\textsubscript{prePRK} – ΔSE\textsubscript{spec}, SimK\textsubscript{prePRK} – ΔSE\textsubscript{spec}, K\textsubscript{prePRK} – ΔSE\textsubscript{corn}, or SimK\textsubscript{prePRK} – ΔSE\textsubscript{corn}) would have resulted in the fewest instances of unexpected hyperopia in this group of patients.

The factor measuring the “real” relative underestimation of the change in the corneal dioptric power following PRK, F-exact, could be calculated for 11 eyes. One eye with 2 IOLs was excluded from this calculation, and, in 3 eyes, the data were insufficient to perform this calculation. This factor, calculated by dividing the calculated “exact” change (ΔK\textsubscript{calc} = K\textsubscript{preCat} – K\textsubscript{meas} = K\textsubscript{prePRK} – K\textsubscript{preCat}), was found to have a mean of 1.74 for the SRK/T formula, 1.63 for the Holladay 1 formula, and 1.42 for the Hoffer Q formula.

F-index, defined as ΔSE\textsubscript{corn}/ΔK\textsubscript{meas}, should theoretically be 1.114 because only the front surface of the cornea is changed by PRK, and regular keratometric and topographic measurements use a keratometric index of 1.3375 for front and back curvature of the cornea combined, instead of the refractive index of the front corneal surface, air to corneal stroma, which is 1.376. This factor could be calculated for 10 eyes and had a mean±SD of 1.44±0.30 (range, 0.68–2.16). The results of the calculation of the different factors, indicating the amount of underestimation of corneal power change measured by keratometry after PRK, are summarized in Table 6. No correlation between these factors and dioptries of refractive change by PRK, or the change in keratometric readings before and after PRK, could be found.

After PRK for myopia, the change in the refractive status of the eye is not accurately reflected in the change in the dioptric power of the cornea as measured by conventional keratometry. Errors in refractive status after cata-

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**Table 1. Patient Characteristics**

<table>
<thead>
<tr>
<th>Patient No./Eye</th>
<th>Sex/Age at PRK, y</th>
<th>Preoperative SE/VA/K Value, Mean, D</th>
<th>Intended Corrections, D/ Treatment Zone, mm</th>
<th>No. of Retreatments</th>
<th>Postoperative (1 Year After Last Treatment) SE/VA/K Value, Mean, D</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/R</td>
<td>M/45</td>
<td>−6.0/0.8/43.0</td>
<td>5.75</td>
<td>0</td>
<td>−0.5/1.0/39.5</td>
<td>NA</td>
</tr>
<tr>
<td>1/L</td>
<td>M/55</td>
<td>−7.0/0.5/44.5</td>
<td>6.5/5</td>
<td>0</td>
<td>−0.75/1.0/39.4</td>
<td>NA</td>
</tr>
<tr>
<td>2/R</td>
<td>F/64</td>
<td>−9.0/0.3/43.2</td>
<td>10/6</td>
<td>0</td>
<td>−0.5/0.7/…</td>
<td>NA</td>
</tr>
<tr>
<td>2/L</td>
<td>F/65</td>
<td>−8.0/0.5/43.5</td>
<td>10/6</td>
<td>1</td>
<td>−3.5/0.3/36.2</td>
<td>Measurement 5 mo after treatment</td>
</tr>
<tr>
<td>3/R</td>
<td>M/49</td>
<td>−9.5/0.8/43.7</td>
<td>10/6</td>
<td>0</td>
<td>−4.25/0.4/38.8</td>
<td>NA</td>
</tr>
<tr>
<td>3/L</td>
<td>M/49</td>
<td>−8.0/0.5/44.0</td>
<td>9/6</td>
<td>0</td>
<td>−5.5/0.4/39.5</td>
<td>NA</td>
</tr>
<tr>
<td>4/R</td>
<td>M/55</td>
<td>−6.0/0.8/40.9</td>
<td>6.0/5</td>
<td>1</td>
<td>−5.0/0.5/35.4</td>
<td>NA</td>
</tr>
<tr>
<td>5/L</td>
<td>M/66</td>
<td>−7.75/0.4/41.25</td>
<td>8.0/...</td>
<td>0</td>
<td>−1.0/0.35/35.25</td>
<td>NA</td>
</tr>
<tr>
<td>6/R</td>
<td>F/29</td>
<td>−6.75/0.5/44.7</td>
<td>...</td>
<td>0</td>
<td>−2.75/0.15/39.5</td>
<td>PRK treatment in other country</td>
</tr>
<tr>
<td>6/L</td>
<td>F/29</td>
<td>−8.0/0.5/44.1</td>
<td>...</td>
<td>0</td>
<td>−0.5/0.5/38.3</td>
<td>PRK treatment in other country</td>
</tr>
<tr>
<td>7/R</td>
<td>M/41</td>
<td>−6.75/1.0/42.4</td>
<td>7.0/...</td>
<td>0</td>
<td>−0.75/0.5/…</td>
<td>NA</td>
</tr>
<tr>
<td>8/R</td>
<td>F/43</td>
<td>−12.0/0.6/41.6</td>
<td>9.9/6</td>
<td>0</td>
<td>0.0/0.6/…</td>
<td>Congenital nystagmus</td>
</tr>
<tr>
<td>8/L</td>
<td>F/42</td>
<td>−11.5/0.6/41.6</td>
<td>9.9/5</td>
<td>0</td>
<td>−0.75/0.5/…</td>
<td>Congenital nystagmus</td>
</tr>
<tr>
<td>9/R</td>
<td>M/51</td>
<td>−7.25/1.0/45.4</td>
<td>6.0/5</td>
<td>0</td>
<td>−0.88/1.0/…</td>
<td>NA</td>
</tr>
<tr>
<td>9/L</td>
<td>M/51</td>
<td>−7.75/1.0/45.5</td>
<td>8.0/5</td>
<td>0</td>
<td>+1.5/0.9/…</td>
<td>NA</td>
</tr>
</tbody>
</table>
Table 2. Clinical Data Regarding Cataract Extraction

<table>
<thead>
<tr>
<th>Patient No./ Eye</th>
<th>Preoperative SE/VA/ K Value, Mean, D</th>
<th>Axial Length, mm</th>
<th>Primary IOL Calculation Method</th>
<th>First IOL Power, D/A Constant</th>
<th>Postoperative SE (After Primary IOL Implantation)</th>
<th>IOL Exchange</th>
<th>Final IOL Power, D/A Constant</th>
<th>Final SE/VA†</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/R</td>
<td>-2.5/0.5/39.7</td>
<td>25.4</td>
<td>5 y 4 mo</td>
<td>Estimated K value†</td>
<td>22.0/118.7</td>
<td>0.0</td>
<td>N</td>
<td>NA</td>
<td>0.0/1.0</td>
</tr>
<tr>
<td>1/L</td>
<td>-0.75/0.7/39.4</td>
<td>25.4</td>
<td>1 y 10 mo</td>
<td>Conventional§</td>
<td>20.0/118.0</td>
<td>+1.0</td>
<td>N</td>
<td>NA</td>
<td>+1.0/1.0</td>
</tr>
<tr>
<td>2/R</td>
<td>-4.5/0.4/39.4</td>
<td>26.1</td>
<td>4 y 4 mo</td>
<td>Based on experience with contralateral eye</td>
<td>22.0/118.0</td>
<td>0.0</td>
<td>N</td>
<td>NA</td>
<td>0.0/0.5</td>
</tr>
<tr>
<td>2/L</td>
<td>-3.5/0.3/36.2</td>
<td>26.0</td>
<td>0 y 5 mo</td>
<td>Conventional§</td>
<td>17.5/118.5</td>
<td>+6.0</td>
<td>Y</td>
<td>22.0/118.0</td>
<td>-0.75/0.3</td>
</tr>
<tr>
<td>3/R</td>
<td>-4.25/0.4/38.8</td>
<td>27.7</td>
<td>1 y 3 mo</td>
<td>Conventional§</td>
<td>16.0/118.5</td>
<td>+2.5</td>
<td>Y</td>
<td>19.0/118.0</td>
<td>-1.5/1.2</td>
</tr>
<tr>
<td>3/L</td>
<td>-5.5/0.3/39.5</td>
<td>27.1</td>
<td>1 y 1 mo</td>
<td>Conventional§</td>
<td>14.5/118.5</td>
<td>+2.5</td>
<td>Y</td>
<td>17.5/118.0</td>
<td>-0.25/1.0</td>
</tr>
<tr>
<td>4/R</td>
<td>-5.0/0.5/35.4</td>
<td>27.5</td>
<td>1 y 7 mo</td>
<td>Conventional§</td>
<td>15.0/117.4</td>
<td>+4.0</td>
<td>Y (2)</td>
<td>21.0/117.4</td>
<td>-0.6/0.8</td>
</tr>
<tr>
<td>5/L</td>
<td>-2.0/0.5/36.3</td>
<td>25.8</td>
<td>2 y 4 mo</td>
<td>Estimated K value‡</td>
<td>24.0/118.7</td>
<td>-0.75</td>
<td>N</td>
<td>NA</td>
<td>-0.5/1.0</td>
</tr>
<tr>
<td>6/R</td>
<td>-3.25/0.2/39.5</td>
<td>24.3</td>
<td>1 y 11 mo</td>
<td>Automated refraction preoperatively, intraoperative exchange IOL</td>
<td>26.0/118.0</td>
<td>-3.0</td>
<td>Y</td>
<td>24.0/118.0</td>
<td>-1.25/0.7</td>
</tr>
<tr>
<td>6/L</td>
<td>-0.75/0.5/38.5</td>
<td>25.0</td>
<td>2 y 6 mo</td>
<td>Based on experience with contralateral eye</td>
<td>23.0/118.7</td>
<td>-0.875</td>
<td>N</td>
<td>NA</td>
<td>+0.9/0.4</td>
</tr>
<tr>
<td>7/R</td>
<td>-1.0/0.5/...</td>
<td>27.0</td>
<td>4 y 4 mo</td>
<td>Automated refraction preoperatively, intraoperative exchange IOL</td>
<td>18.0/118.7</td>
<td>...</td>
<td>Y</td>
<td>20.0/118.7</td>
<td>+0.5/0.7</td>
</tr>
<tr>
<td>8/R</td>
<td>0.0/0.15§†/34.4</td>
<td>29.5</td>
<td>3 y 4 mo</td>
<td>Rule of thumb§§</td>
<td>21.0/118.0</td>
<td>0.0</td>
<td>N</td>
<td>NA</td>
<td>0.0/0.2†</td>
</tr>
<tr>
<td>8/L</td>
<td>0.0/0.15§†/37.4</td>
<td>28.9</td>
<td>3 y 2 mo</td>
<td>Rule of thumb§§</td>
<td>20.0/118.0</td>
<td>0.0</td>
<td>N</td>
<td>NA</td>
<td>0.0/0.3§</td>
</tr>
<tr>
<td>9/R</td>
<td>-2.6/0.25/38.9</td>
<td>25.9</td>
<td>2 y 11 mo</td>
<td>Conventional§</td>
<td>19.0/118.0</td>
<td>+3.75</td>
<td>Y (IOL added)</td>
<td>6.0/118.0  (piggyback, sulcus)</td>
<td>0.0/0.8</td>
</tr>
<tr>
<td>9/L</td>
<td>-4.0/0.3/41.3</td>
<td>26.1</td>
<td>4 y 5 mo</td>
<td>Based on experience with contralateral eye</td>
<td>25.0/118.0</td>
<td>-1.5</td>
<td>N</td>
<td>NA</td>
<td>-1.5/0.4</td>
</tr>
</tbody>
</table>

*SE indicates spherical equivalent of subjective refraction at the spectacle plane; VA, visual acuity; PRK(Cat), time from final photorefractive keratotomy treatment to cataract surgery; IOL, intraocular lens; D, diopter; K, keratometric; RD, retinal detachment; PCO, posterior capsule opacification; ellipses, missing data; and NA, not applicable.

†VA was measured in Snellen lines.
‡K value was estimated (flatter than a measured K value) by subtracting the achieved refraction at the corneal and/or spectacle plane from the original K value, and by correcting the change in K value by 11.4% and averaging these calculated K values.
§The standard formula (in each surgery center) was applied, using the mean K value measured after PRK and before cataract extraction.
¶The IOL power used in emmetropic eyes ("standard IOL") was taken after correction for residual refractive error post-PRK.
¶¶VA was measured with the other eye occluded.

Table 3. Difference Between Actual (Achieved) Refraction After Final IOL Implantation and Predicted Refraction

<table>
<thead>
<tr>
<th>K Value Calculation Method†</th>
<th>No. of Eyes</th>
<th>SRK/T</th>
<th>Holladay 1</th>
<th>Hoffer Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>K(preCat)</td>
<td>13</td>
<td>+2.8 ± 2.0 (±0.4 to +6.6)</td>
<td>+2.8 ± 2.1 (0.0 to +6.4)</td>
<td>+1.9 ± 2.0 (−0.5 to +6.0)</td>
</tr>
<tr>
<td>SimK(preCat)</td>
<td>10</td>
<td>+2.5 ± 2.3 (−0.5 to +6.2)</td>
<td>+2.3 ± 2.5 (−1.0 to +6.4)</td>
<td>+1.5 ± 2.4 (−1.4 to +5.5)</td>
</tr>
<tr>
<td>Mink(preCat)</td>
<td>9</td>
<td>+1.8 ± 2.5 (−1.6 to +5.7)</td>
<td>+1.5 ± 2.7 (−2.1 to +5.8)</td>
<td>+0.7 ± 2.6 (−2.7 to +4.9)</td>
</tr>
<tr>
<td>K(prePRK) - ΔSE(corn)</td>
<td>10</td>
<td>+0.7 ± 0.8 (−0.3 to +2.2)</td>
<td>+0.3 ± 0.8 (−0.8 to +1.6)</td>
<td>−0.6 ± 0.9 (−1.8 to +0.8)</td>
</tr>
<tr>
<td>SimK(prePRK) - ΔSE(corn)</td>
<td>10</td>
<td>+1.3 ± 0.9 (−0.3 to +2.7)</td>
<td>+1.0 ± 1.0 (−0.2 to +2.7)</td>
<td>+0.1 ± 0.8 (−1.2 to +1.2)</td>
</tr>
<tr>
<td>K(prePRK) - ΔSE(spec)</td>
<td>6</td>
<td>+0.6 ± 0.9 (−0.7 to +1.9)</td>
<td>+0.2 ± 0.9 (−1.3 to +1.4)</td>
<td>−1.0 ± 1.0 (−2.4 to +0.3)</td>
</tr>
<tr>
<td>SimK(prePRK) - ΔSE(spec)</td>
<td>6</td>
<td>+1.4 ± 1.0 (−0.2 to +2.5)</td>
<td>+1.1 ± 1.1 (−0.8 to +2.3)</td>
<td>−0.1 ± 0.9 (−1.8 to +0.9)</td>
</tr>
<tr>
<td>K(prePRK) - 1.114 × ΔK(meas)</td>
<td>11</td>
<td>+2.2 ± 2.2 (−0.3 to +6.2)</td>
<td>+1.9 ± 2.4 (−0.7 to +6.0)</td>
<td>+1.1 ± 2.2 (−0.9 to +5.9)</td>
</tr>
</tbody>
</table>

*IOL indicates intraocular lens; D, diopter; and K, keratometric.
†Detailed explanations of K value calculation methods provided in Figure 1.

IOL extraction following excimer laser surgery have been reported in a few case reports and case series.6-11 In these reports, underestimation of the IOL power needed to achieve emmetropia caused erroneous hyperopic outcomes. In this study, too, use of uncorrected keratometric values, measured after PRK and before cataract extraction, underestimation of the IOL power needed to...
mal eyes. More important, Mandell argued that only the parameters in eyes treated by PRK differed significantly from normal.

The authors found that the difference between the 2 parameters in eyes treated by PRK differed significantly from normal. More important, Mandell argued that only the change induced by PRK in the front surface of the cornea should be considered; therefore the refractive index of corneal stroma (ie, 1.376) should be used instead of the currently used index of 1.3375 for front and back curvature combined.

Several authors therefore advocate using a correcting factor of 1.14, or adding 11.4% to the difference in regular or computerized keratometer readings that are taken with an instrument using the keratometer index of 1.3375 before and after PRK. In our study, we found “correcting factors” of 1.42 to 1.74, depending on the method of calculation, which indicates a mean underestimate of the change in K value after PRK of at least 42%, instead of 11.4%.

Seitz et al performed a study on 31 eyes before and after PRK for myopia of 1.5 D to 8 D (mean ± SD, 5.4 D ± 1.9 D). The authors compared keratometric and topographic measurements after PRK with corrected post-PRK K values. The relative flattening of the cornea appeared to be underestimated by 14% to 30% (mean, 24%) depending on the method of calculation. The measured corneal power after PRK was significantly greater than the calculated corneal power. Powers of IOLs were calculated using corrected K values in the SRK/T and Haigis formulas. The calculated corneal power using the SE change of refraction at the corneal plane was suggested to be most appropriate on theoretical grounds. Corneal power overestimation and IOL power underestimation correlated significantly with the SE change after PRK and with intended ablation depth. These calculations were based on the comparison of changes in the corneal curvature before and after PRK, calculating theoretical differences in IOL power, and not on actual clinical data after cataract extraction. The average preoperative refraction prior to PRK in our study was –8.2 D. This is in contrast with the eyes studied by Seitz et al, in which the mean preoperative refraction was –5.4 D. These authors found a correlation between the corneal power overestimation and the SE change induced by PRK. Considering the relationship between the amount of myopia that was corrected and the relative underestimate, it can be predicted that the underestimate will be even larger after LASIK procedures for high myopia. In our study group, however, we did not find this correlation. More research is needed in this area.

Two tentative conclusions can be drawn. Apparently, the factor of 11.4% that was initially proposed to
correct the keratometric change induced by PRK is too low. Second, because of the large range in relative underestimation of corneal power change, the use of a fixed correcting factor (eg, 1.114, 1.42, or 1.74) for the measured keratometric change after PRK will probably result in an equally large range of refractive outcomes after cataract surgery and is therefore not advocated. However, larger prospective studies are needed to confirm our conclusions.

In third-generation formulas, such as Holladay 1 and 2, Hoffer Q, and SRK/T, the keratometric value is used to estimate the postoperative anterior chamber depth or effective lens position (ELP) of the IOL. However, a patient with a given K value who has never had refractive surgery probably has a different ELP than a patient with the same (measured or calculated) K value after laser vision correction. One should be aware that in calculating a correcting factor for the keratometric change using one of these formulas, a certain amount of circular reasoning may be present because these formulas use the K value to estimate the ELP. Perhaps the better outcomes using spectacle instead of corneal plane refraction in this study simply reflect the fact that assumptions in these formulas about the relationship between ELP and keratometric measurements in normal eyes are no longer valid in postrefractive surgery eyes. In the Holladay 2 formula, the ELP is further estimated by taking into account the preoperative white-to-white measurement, anterior chamber depth, and lens thickness. In our retrospective study, these parameters were not available, and, therefore, we could not use this formula. We do recommend use of the Holladay 2 formula in further studies because it may be more accurate in “nonstandard” situations, such as in eyes after refractive surgery.

In our study, with regard to the different IOL calculation formulas, no consistently better or worse formula could be identified to achieve a refraction within 1 D of the predicted refraction. To avoid large unexpected refractive errors, the formula used seemed less important than the method of calculating the appropriate K value. However, to avoid postoperative hyperopia, the Hoffer Q formula seems to be superior to the SRK/T and Holladay 1 formulas. This is important because postoperative hyperopia will be even less tolerated than postoperative myopia.

This study has limitations. Although, to our knowledge, the number of eyes presented in this study is the largest series thus far, it is still a low number, and, from most patients, both eyes were included. Statistics were not applied because of these 2 factors. Other methods to determine the correct refractive corneal power after PRK, such as the contact lens over refraction method or methods using the Stiles-Crawford effect or ray-tracing techniques, were not employed in this study and may prove superior. Zeh and Koch23 showed that in a study group of normal eyes, the method of contact lens overrefraction is less accurate when visual acuity is decreased due to cataract. Even so, for patients whose original pre-PRK values have been lost over time, this method may well prove its value in the future.

Intraoperative autorefractometry gave satisfactory outcomes in 2 eyes in this study. The clinical applicability of this method may be limited because autorefractometry is less reliable after PRK than in normal eyes. This is also the case after LASIK. Other methods used to achieve an acceptable refractive outcome in several difficult situations (cataract surgery after radial keratotomy or after penetrating keratoplasty) have been described. In our series, IOL exchange and adding a piggyback IOL were successfully performed without serious complications.

Using actual clinical refractive outcomes after cataract extraction following PRK, we studied which method of K value calculation was most suitable to use in IOL power calculation formulas. In any case, correcting the measured K value with the refractive change after PRK increased accuracy and decreased the chance of unexpected hyperopia. We found the spectacle plane/refractive change–corrected K values to be most accurate. The Hoffer Q formula was superior to the SRK/T and Holladay 1 formulas in avoiding a large hyperopic outcome. We must, however, be aware that considerable ranges in outcome occur and larger numbers of patients are needed before a definite answer can be given to the question of which method of IOL calculation is best after prior PRK.

Based on this study and our clinical experience, we offer the following recommendations:

- Patients should be informed that they need to mention prior corneal refractive surgery to their ophthalmologist when cataract surgery is proposed.
- Patients should be given a “wallet card” with their K values and spectacle refraction measured prior to PRK and 1 year after PRK. Axial length measurements could also be included to make it easier to differentiate in the future among corneal regression, an increase in myopia due to lenticular sclerosis, and an increase in axial length.
- In case of a significant change in refraction after PRK, every attempt should be made to differentiate between myopic change due to (late) regression of the induced change after PRK, and an increase in axial length, or nuclear cataract, and to document this appropriately.
- To calculate the appropriate IOL for implantation, measured K values after PRK overestimate corneal power. We recommend replacing these measured K values with a value obtained by correcting the K value measured before PRK with the change in refraction (SE) due to PRK at the spectacle plane. This should be measured about 1 year after PRK and before the development of cataract and/or an increase in myopia due to lenticular sclerosis.
- Use of the Hoffer Q formula will probably result in less unexpected hyperopia.
- Patients who are eligible for cataract surgery after PRK should be informed that, thus far, the methods used to calculate IOL power are not fully adapted to the situation after PRK and an IOL exchange or other additional intervention may be necessary to achieve emmetropia.
REFERENCES