Use of the Posterior/Anterior Corneal Curvature Radii Ratio to Improve the Accuracy of Intraocular Lens Power Calculation: Eom’s Adjustment Method

Mingue Kim, Youngsub Eom, Hwa Lee, Young-Woo Suh, Jong Suk Song, and Hyo Myung Kim
Department of Ophthalmology, Korea University College of Medicine, Seoul, South Korea

PURPOSE. To evaluate the accuracy of IOL power calculation using adjusted corneal power according to the posterior/anterior corneal curvature radii ratio.

METHODS. Nine hundred twenty-eight eyes from 928 reference subjects and 158 eyes from 158 cataract patients who underwent phacoemulsification surgery were enrolled. Adjusted corneal power of cataract patients was calculated using the fictitious refractive index that was obtained from the geometric mean posterior/anterior corneal curvature radii ratio of reference subjects and adjusted anterior and predicted posterior corneal curvature radii from conventional keratometry (K) using the posterior/anterior corneal curvature radii ratio. The median absolute error (MedAE) based on the adjusted corneal power was compared with that based on conventional K in the Haigis and SRK/T formulae.

RESULTS. The geometric mean posterior/anterior corneal curvature radii ratio was 0.808, and the fictitious refractive index of the cornea for a single Scheimpflug camera was 1.3275. The mean difference between adjusted corneal power and conventional K was 0.05 diopter (D). The MedAE based on adjusted corneal power (0.31 D in the Haigis formula and 0.40 D in the SRK/T formula) was significantly smaller than that based on conventional K (0.41 D and 0.40 D, respectively; \( P < 0.001 \) and \( P < 0.001 \), respectively). The percentage of eyes with refractive prediction error within \( \pm 0.50 \) D calculated using adjusted corneal power (74.7%) was significantly greater than that obtained using conventional K (62.7%) in the Haigis formula (\( P = 0.029 \)).

CONCLUSIONS. IOL power calculation using adjusted corneal power according to the posterior/anterior corneal curvature radii ratio provided more accurate refractive outcomes than calculation using conventional K.

Keywords: intraocular lens, calculation, corneal power, posterior corneal radius, cataract

IOL power calculation comprises three main parts: measurement of corneal power, estimation of effective lens position, and measurement of axial length (AL).\(^1\)\(^-\)\(^3\) Of these three components, corneal power can be obtained from corneal thickness and anterior and posterior corneal curvature radii. However, in the past, clinical data regarding the posterior corneal curvature radius were not available. Thus, corneal refractive power was traditionally estimated from anterior corneal measurements, keratometry (K), using a fictitious refractive index of the cornea under the assumption that the posterior/anterior corneal curvature radii ratio is constant.\(^4\)

Conventional K has become the gold standard for corneal thickness and anterior and posterior corneal curvature radii. However, there was no improvement in the accuracy of IOL power calculation in normal eyes when corneal power measurements from a Scheimpflug camera were applied directly.\(^8\)

We hypothesized that if conventional K can be adjusted according to the posterior/anterior corneal curvature radii ratio without changing the mean value of the entire data set, the adjusted corneal power could reduce the refractive prediction error created by the assumption that the posterior/anterior corneal curvature radii ratio is constant in IOL power calculation. This study introduces a method for adjusting conventional K according to the posterior/anterior corneal curvature radii ratio without changing the mean value of the entire data set. The aim of this study was to evaluate the accuracy of IOL power calculation using adjusted corneal power according to the posterior/anterior corneal curvature radii ratio.

**MATERIALS AND METHODS**

**Study Population**

This retrospective cross-sectional study included 928 eyes of 928 reference subjects and 158 eyes of 158 cataract patients.
The Institutional Review Board of Korea University Ansan Hospital, Gyeonggi, Korea, approved this study. All research and data collection adhered to the tenets of the Declaration of Helsinki.

Electronic medical records of all subjects who underwent measurement with a single Scheimpflug camera (Pentacam; Oculus Optikgeräte, Wetzlar, Germany) at our institution between May 1, 2009, and January 31, 2015, were reviewed. Reference subjects were selected based on the results of a single Scheimpflug examination as previously described. Exclusion criteria included (1) age younger than 50 years, (2) a history of previous ocular surgery, (3) presence of corneal disease (such as keratoconus) or other corneal pathologies that could affect Scheimpflug measurement, or (4) use of a contact lens within 3 weeks prior to measurement.

One hundred fifty-eight consecutive patients who underwent uncomplicated phacoemulsification with implantation of an IOL (Tecnis ZCB00 IPiece; Abbott Medical Optics, Inc., Santa Ana, CA, USA) at our institution between March 1, 2013, and October 31, 2016, were enrolled. Patients with preoperative measurements from a single Scheimpflug camera with good-quality states (quality okay mark displayed on Pentacam maps) and with a best-corrected visual acuity (BCVA) ≥20/40 in the operated eye after cataract surgery were included. Eyes with a history of previous ocular surgery (e.g., penetrating keratoplasty or refractive surgery), corneal diseases such as keratoconus, corneal pathologies that could affect Scheimpflug measurements, traumatic cataract, sulcus fixed IOLs, IOL exchanges, or postoperative complications were excluded.

**Patient Examination**

In 928 reference subjects, anterior and posterior corneal curvature radii and central corneal thickness were measured using a single Scheimpflug camera. In 158 cataract patients, preoperative K, anterior chamber depth (ACD), and AL were measured using an optical biometer (IOLMaster 500, version 7.5; Carl Zeiss Meditec, Jena, Germany). In addition, preoperative anterior and posterior corneal curvature radii were measured using a single Scheimpflug camera, and the true net power and total corneal refractive power of the 1.0- to 6.0-mm apex zone were extracted from the power distribution report. Postoperative uncorrected distance visual acuity (BCVA), objective refraction measured with an autorefractor/kerometer (KR-8100; Topcon, Tokyo, Japan), and subjective refraction were measured at visits between 4 and 8 weeks after cataract surgery.

**Surgical Technique**

All phacoemulsification with IOL implantation procedures were performed under topical anesthesia with 0.5% proparacaine hydrochloride (Paracaine; Hanmi Pharm, Seoul, Korea) by one of three experienced surgeons. A 2.75-mm clear corneal incision was made, and a continuous curvilinear capsulorhexis slightly smaller than the IOL optic size was created with a 26-gauge needle and capsulorhexis forceps. A standard phacoemulsification technique was used, and the IOL was inserted into the capsular bag using an injector system.

**Main Outcome Measures**

**Fictitious Refractive Index of the Cornea for a Single Scheimpflug Camera.** Single Scheimpflug measurements of 928 reference subjects were obtained. The geometric mean posterior/anterior corneal curvature radii ratio, mean anterior corneal curvature radius, mean central corneal thickness, thick lens formula, and thin lens formula were used to calculate the fictitious refractive index of the cornea for a single Scheimpflug camera as follows:

\[
D_A = \frac{\left( n_{\text{cornea}} - 1 \right) \times 1000}{r_{\text{cornea}}} \tag{1}
\]

\[
D_P = \frac{\left( n_{\text{aqueous}} - n_{\text{cornea}} \right) \times 1000}{r_{\text{cornea}} \times R_{PA}} \tag{2}
\]

\[
D_{\text{Total}} = D_A + D_P - \frac{T}{n_{\text{cornea}} \times 1000} \times D_A \times D_P \tag{3}
\]

\[
n_c = \frac{D_{\text{Total}} \times r_{\text{cornea}}}{1000} + 1 \tag{4}
\]

where \(D_A\) is the dioptic power of the anterior corneal surface, \(n_{\text{cornea}}\) is the refractive index of the cornea (1.376), \(r_{\text{cornea}}\) is the mean anterior corneal curvature radius, \(D_P\) is the dioptic power of the posterior corneal surface, \(n_{\text{aqueous}}\) is the refractive index of the aqueous (1.336), \(R_{PA}\) is the geometric mean posterior/anterior corneal curvature radii ratio, \(D_{\text{Total}}\) is the dioptic power of the total cornea, \(T\) is the mean central corneal thickness, and \(n_c\) is the fictitious refractive index of the cornea for a single Scheimpflug camera.

**Adjustment of Conventional K.** In 158 cataract patients, the adjusted anterior corneal curvature radius and the predicted posterior corneal curvature radius were calculated using the fictitious refractive index of the cornea for a single Scheimpflug camera. K measurements of the IOLMaster, and the posterior/anterior corneal curvature radii ratio as follows:

\[
r_A = \frac{\left( n_c - 1 \right) \times 1000}{D_{\text{Total}}} \tag{5}
\]

\[
r_P = r_A \times R_{PA} \tag{6}
\]

where \(r_A\) is the adjusted anterior corneal curvature radius, \(n_c\) is the fictitious refractive index of the cornea for a single Scheimpflug camera, \(D_{\text{Total}}\) is the dioptic power of K measurements of the IOLMaster, \(r_P\) is the predicted posterior corneal curvature radius, and \(R_{PA}\) is the posterior/anterior corneal curvature radii ratio.

Adjusted corneal power was calculated using a thick lens formula based on the adjusted anterior corneal curvature radius, predicted posterior corneal curvature radius, refractive indices of cornea and aqueous humor (1.376 and 1.336, respectively), and central corneal thickness.

**Optimization of Haigis Constants and the SRK/T A-Constant.** The data-adjusted \(a_0\), \(a_1\), and \(a_2\) constants for the Haigis formula were calculated with linear regression analysis using the back-calculated effective lens position in order to obtain zero mean arithmetic error in IOL power prediction.

The back-calculated effective lens position was defined as the postoperatively calculated effective lens position based on preoperative K, AL, implanted IOL power, and postoperative refraction.

**Refractive Prediction Error.** The median absolute error (MedAE) was defined as the median absolute value of the refractive prediction error. The refractive prediction error was defined as the difference between the refractive spherical equivalent observed 4 to 8 weeks after surgery and the preoperative predicted refraction determined using the Haigis and SRK/T formulae (refractive prediction error = postoperative spherical equivalent – preoperative predicted refraction).
tests were performed to determine whether there was a statistically significant difference in the ratio of refractive prediction error. A post hoc power analysis using the $\chi^2$-square tests option of G*$power (version 3.1.9.2; Franz Paul, Kiel, Germany) was conducted to determine study power. P values less than 0.05 were considered statistically significant.

**Results**

Of 928 reference subjects, mean age was 52.7 ± 11.8 years (range, 30–89 years), and there were 484 males (52.2%) and 466 left eyes (50.2%). The geometric mean anterior/posterior corneal curvature radii was 0.808. Mean anterior corneal curvature radius was 7.71 mm, and mean central corneal thickness was 0.565 mm. Based on these results, the fictitious refractive index of the cornea for a single Scheimpflug camera was calculated as 1.3275. Of 158 cataract patients, the mean age of subjects was 68.5 ± 11.0 years (range, 30–88 years). There were 89 females (56.3%) and 87 left eyes (55.1%). The mean adjusted corneal power was 44.35 ± 1.78 diopter (D), and the mean difference between adjusted corneal power and conventional K was 0.05 ± 0.21 D. Preoperative K, ACD, and AL measured via IOLMaster and anterior/posterior corneal curvature radii using a single Scheimpflug camera are shown in Table 1.

In spite of IOL constant optimization, the refractive prediction error derived from the use of conventional K became more myopic as the posterior/anterior corneal curvature radii ratio increased in both the Haigis and SRK/T formulae (Figs. 2A, 2B); however, no correlation and/or a decreased correlation was observed between the refractive prediction error and the posterior/anterior corneal curvature radii ratio when adjusted corneal power was used in the IOL power calculation (Figs. 2C, 2D).

Table 2 shows MedAE and mean refractive prediction error as determined by two different methods, one using adjusted corneal power, the other using conventional K. The MedAE predicted using the adjusted corneal power (0.31 D in the Haigis formula and 0.32 D in the SRK/T formula) was significantly smaller than that predicted using conventional K (0.41 D in the Haigis formula and 0.40 D in the SRK/T formula;
The percentage of eyes that achieved a postoperative refractive prediction error within \( \pm 0.50 \) D from the preoperative predicted refraction was 62.7\%, when conventional K was used in the Haigis formula. This percentage improved significantly to 74.7\% when adjusted corneal power was applied to the Haigis formula (\( P = 0.029 \)).

In a post hoc power analysis, the calculated effect size from the percentage of eyes within \( \pm 0.50 \) D of the refractive prediction error was 0.248. The effect size of 0.248 and \( \alpha \) of 0.05 with 158 patients led to a power of 0.88.

All MedAEs predicted using the true net power and total corneal refractive power were significantly greater than that...
predicted using conventional K in the Haigis formula (all $P < 0.05$; Fig. 3). In the SRK/T formula, all MedAEs predicted using
the true net power and total corneal refractive power were
significantly greater than that predicted using conventional K,
element the true net power and total corneal refractive power of
the 2.0-, 3.0-, and 4.0-mm apex zone (Fig. 4).

In subgroup analysis, there were no significant differences
in MedAE and the percentage of eyes with refractive prediction
error within $\pm 0.50$ D calculated using conventional K and
adjusted corneal power in the middle 50% of the data group.
In contrast, MedAE predicted using adjusted corneal power (0.31
D in the Haigis formula and 0.38 D in the SRK/T formula) was
significantly smaller than that predicted using conventional K
(0.44 D in the Haigis formula and 0.52 D in the SRK/T formula;
$P < 0.001$ and $P < 0.001$, respectively) in the upper and lower
25% of the data group. In addition, the percentage of eyes with
refractive prediction error within $\pm 0.50$ D calculated using
adjusted corneal power was significantly greater than that
obtained using conventional K in both the Haigis and SRK/T
formulas in the upper and lower 25% of the data group (Tables
3, 4).

**DISCUSSION**

This study suggests a method for adjusting conventional K
according to the posterior/anterior corneal curvature radii
ratio without changing the mean value of the entire data set
and calculated IOL power using this adjusted corneal power.
The results of this study showed that IOL power calculation
using the adjusted corneal power obtained through our
method provides a more accurate estimate of refractive
outcomes than IOL power calculation using conventional K.
In addition, this study introduced the K-adjusted IOL power
calculator. Thus, the user can easily calculate IOL power and
can predict postoperative refraction using this K-adjusted IOL
power calculator in order to apply the posterior/anterior
corneal curvature radii ratio to conventional K in IOL power
calculation.

In this study, refractive prediction error was significantly
correlated with the posterior/anterior corneal curvature radii
ratio when conventional K was used, while there was no
association or a decreased correlation between the refractive
prediction error and the posterior/anterior corneal curvature
radii ratio when adjusted corneal power was used. This
indicates that the bias in refractive prediction error derived
from the use of conventional K could be eliminated by using
adjusted corneal power. Consistent with our results, Miyata
et al. demonstrated a significant association between the
refractive prediction error and posterior corneal curvature
when single Scheimpflug imaging was not included in IOL
power calculation.

Similar to this study’s method and findings, previous studies
introduced a theoretical variable keratometric index according
to the anterior corneal curvature radius for normal eyes and
demonstrated that using the variable keratometric index
could improve refractive outcomes after multifocal IOL
implantation. IOL power calculation using adjusted corneal
power calculated with the variable keratometric index also
improved refractive outcomes in eyes with a history of
previous refractive corneal surgery after cataract surgery.

There were no improvements in refractive outcomes when
we applied the true net power and total corneal refractive
power from Pentacam directly to IOL power calculation
despite IOL constant optimization; instead, outcomes were
worse in many cases. In line with this study, previous studies
also found no superiority using the corneal power derived
from both the anterior and posterior corneal measurements of
a single Scheimpflug camera relative to using simulated K in
IOL power calculation for normal eyes and demonstrated that
using the variable keratometric index could improve refractive
outcomes after multifocal IOL implantation. IOL power calculation using adjusted corneal
power calculated with the variable keratometric index also
improved refractive outcomes in eyes with a history of
previous refractive corneal surgery after cataract surgery.
Ray tracing is the gold standard method for calculating the path of rays in lenses and optical systems, and previous studies have used ray tracing in IOL power calculation. Ray-tracing IOL power calculations in normal eyes showed comparable accuracy compared to the conventional formula, although the refractive outcomes obtained by applying the true net power and total corneal refractive power to IOL power calculation were worse than those obtained using conventional K in this study. In addition, in eyes with prior myopic ablation, ray-tracing IOL power calculation provided accurate refractive outcomes similar to those in eyes without prior surgery. Ray-tracing IOL power calculation does not use the fictitious refractive index for corneal power calculation. On the other hand, the method used in this study relies on the introduced fictitious refractive index of the cornea for a single Scheimpflug camera to adjust IOLMaster K according to the posterior/anterior corneal curvature radii ratio. Therefore, the refractive outcomes from ray-tracing IOL power calculation are more accurate than the method used in this study. However, devices that perform ray-tracing IOL power calculation are not available in all eye clinics, and many ophthalmologists are most familiar with conventional formulae. Thus, we sought to reduce error caused by the conventional method by creating a method that would be useful in clinics where IOL power calculation via optical ray tracing are not available.

IOL constants used in IOL power calculation formulae are optimized for conventional K because conventional K is the gold-standard biometry in IOL power calculation. In order to avoid altering the IOL constants of various formulae, this study introduced a method that adjusts conventional K without changing the mean value for the entire data set. When optimized IOL constants were applied to IOL power calculation, a nearly zero mean arithmetic error was obtained for IOL power prediction with not only conventional K but also with adjusted corneal power. As a result, the accuracy of IOL power calculation could be improved using adjusted corneal power based on our method with original IOL constants derived from conventional K.

Although the accuracy of IOL power calculation significantly improved when using adjusted corneal power, the magnitude of improvement in MedAE (0.10 D in the Haigis formula and 0.08 D in the SRK/T formula) may not have clinical relevance. Although modern IOL power calculation formulae provide similarly excellent refractive outcomes in eyes with average AL, refractive outcomes become less accurate in eyes that deviate from the average posterior/anterior corneal curvature radii ratio. In fact, the magnitude of improvement in MedAE using adjusted corneal power increased up to 0.13 D in the Haigis formula and 0.14 D in the SRK/T formula in the upper and lower 25% of data when patients were divided into two groups according to the lower (25th) and upper quartile (75th) of the posterior/anterior corneal curvature radii ratio. In contrast, there was no improvement in MedAE in the middle 50% of the data. Consistent with this study, direct application of corneal power derived from both the anterior and posterior corneal measurements to IOL power calculation improved refractive outcomes in eyes with posterior keratoconus that deviated from the average posterior/anterior corneal curvature radii ratio but not in normal eyes. Thus, IOL power calculation using the adjusted corneal power developed in this study might have clinical benefit, especially in eyes that deviate from the average posterior/anterior corneal curvature radii ratio.
There are some limitations to this study. First, our method was retrospectively tested in 158 cataract eyes, although our reference refractive index for the cornea was obtained via single Scheimpflug camera data from 928 reference subjects. Second, this study used a single acquisition by a single Scheimpflug camera to adjust corneal power. There is the possibility of error occurring when using a single acquisition by a single Scheimpflug measurement, even though this study

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**Table 3.** Comparison of MedAE and RE Based on the Posterior/Anterior Corneal Curvature Radii Ratio Between Calculations Using Conventional K and Those Using Adjusted Corneal Power in the Haigis Formula

<table>
<thead>
<tr>
<th>Ratio_{PA} ≤ Q1 or &gt; Q3 (n = 79)</th>
<th>Conventional K</th>
<th>Adjusted Corneal Power</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MedAE, D* (0.22:0.63)</td>
<td>0.44 (0.22:0.63)</td>
<td>0.31 (0.17:0.48)</td>
<td>&lt;0.001‡</td>
</tr>
<tr>
<td>MAE, D† (0.29)</td>
<td>0.46 (0.29)</td>
<td>0.35 (0.24)</td>
<td>&lt;0.001§</td>
</tr>
<tr>
<td>RE, D (range)</td>
<td>0.04 (–1.01 to 1.25)</td>
<td>0.09 (–0.87 to 1.01)</td>
<td>0.007</td>
</tr>
<tr>
<td>≥0.25 D, n (%)</td>
<td>22 (27.8)</td>
<td>34 (43.0)</td>
<td></td>
</tr>
<tr>
<td>≥0.50 D, n (%)</td>
<td>44 (55.7)</td>
<td>61 (77.2)</td>
<td></td>
</tr>
<tr>
<td>≥0.75 D, n (%)</td>
<td>67 (84.8)</td>
<td>72 (91.1)</td>
<td></td>
</tr>
<tr>
<td>&gt;≥1.00 D, n (%)</td>
<td>4 (5.1)</td>
<td>1 (1.3)</td>
<td></td>
</tr>
<tr>
<td>Q1 &lt; Ratio_{PA} ≤ Q3 (n = 79)</td>
<td>Conventional K</td>
<td>Adjusted Corneal Power</td>
<td>P Value</td>
</tr>
<tr>
<td>MedAE, D* (0.18:0.55)</td>
<td>0.36 (0.18:0.55)</td>
<td>0.34 (0.17:0.53)</td>
<td>0.126‡</td>
</tr>
<tr>
<td>MAE, D† (0.33)</td>
<td>0.41 (0.33)</td>
<td>0.40 (0.32)</td>
<td>0.130§</td>
</tr>
<tr>
<td>RE, D (range)</td>
<td>−0.05 (–1.27 to 1.94)</td>
<td>0.01 (–1.23 to 1.95)</td>
<td>0.861</td>
</tr>
<tr>
<td>≥0.25 D, n (%)</td>
<td>29 (36.7)</td>
<td>29 (36.7)</td>
<td></td>
</tr>
<tr>
<td>≥0.50 D, n (%)</td>
<td>55 (69.6)</td>
<td>57 (72.2)</td>
<td></td>
</tr>
<tr>
<td>≥0.75 D, n (%)</td>
<td>68 (86.1)</td>
<td>67 (84.8)</td>
<td></td>
</tr>
<tr>
<td>&gt;≥1.00 D, n (%)</td>
<td>3 (3.8)</td>
<td>3 (3.8)</td>
<td></td>
</tr>
</tbody>
</table>

Q1, lower quartile (25th) of Ratio_{PA}; Q3, upper quartile (75th) of Ratio_{PA}.

* Values are presented as median (interquartile range).
† Values are presented as mean (SD).
‡ Wilcoxon signed-rank test.
§ Paired t-test.
|| χ² square test.
used scans with good quality states and Pentacam measurements of both anterior and posterior corneal curvature radii showed good repeatability and reliability.\textsuperscript{[12,19,30]} Thus, a prospective study with a large number of cataract eyes that have multiple measurements of a single Scheimpflug camera will be needed to address whether IOL power calculation using adjusted corneal power based on the posterior/anterior corneal curvature radii ratio is superior to that using conventional K.

In conclusion, IOL power calculation using adjusted corneal power based on the posterior/anterior corneal curvature radii ratio might more accurately predict postoperative refraction than that using conventional K. To apply posterior corneal curvature radii ratio might more accurately predict postoperative refraction power based on the posterior/anterior corneal curvature radii ratio. Adjusted IOL power calculation could be used in the K-adjusted IOL power calculator developed in this study.

### References


### Table 4

<table>
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<tr>
<th>Comparison of MedAE and RE Based on the Posterior/Anterior Corneal Curvature Radii Ratio Between Calculations Using Conventional K and Those Using Adjusted Corneal Power in the SRK/T Formula</th>
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<td><strong>Q1 &lt; RATIO _PA ≤ Q3 (n = 79)</strong></td>
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<td>&gt;±1.00 D, n (%)</td>
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*Values are presented as median (interquartile range).
†Values are presented as mean (SD).
‡Wilcoxon signed-rank test.
§Paired t-test.
||χ²-test.


