Effect of Soft Contact Lenses on Optical Measurements of Axial Length and Keratometry for Biometry in Eyes with Corneal Irregularities

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PURPOSE. To assess the repeatability and reliability of IOLMaster (Carl Zeiss Meditec, Inc., Dublin, CA) axial length and keratometry measurements (K readings) with a soft contact lens on normal eyes. The method is designed for eyes with corneal irregularities or after endothelial keratoplasty.

METHODS. Biometry was performed on 20 healthy right eyes of volunteer subjects with mean age, 27.3 ± 4.9 years; axial length, 24.77 ± 1.04 mm; and K reading, 43.48 ± 1.69 D. Axial length and keratometry were measured and repeated with −0.5 D SofLens38 (Bausch & Lomb, Rochester, NY) and Acuvue2 (Johnson & Johnson, New Brunswick, NJ) soft contact lenses. Repeatability and reliability were evaluated. Contact lens thickness was measured directly by corneal optical coherence tomography (OCT).

RESULTS. Axial lengths increased 59 ± 10 μm with SofLens38 and 134 ± 13 μm with Acuvue2, and these changes correlated with the OCT contact lens thicknesses (P = 0.995). The axial length variability remained constant (P = 0.18), measuring 24 ± 10 μm for SofLens38 and 23 ± 8 μm for Acuvue2 compared with 20 ± 7 μm with no lens. K readings of 43.08 ± 1.66 D with SofLens38, 42.79 ± 1.57 D with Acuvue2, and 43.48 ± 1.69 D with no lens corresponded to differences of −0.40 ± 0.12 D with SofLens38 and −0.69 ± 0.19 D with Acuvue2. The K-reading variability increased slightly from 0.04 to 0.09 D with either lens.

CONCLUSIONS. Low-power soft contact lenses enable reliable and repeatable IOLMaster axial length and K-reading measurements. Correcting for the measurable lens thickness and lens effects, a <0.5-D error in the Sanders-Retzlaff-Kraff (SRK) II power formula is predicted. (Invest Ophthalmol Vis Sci. 2008; 49:3371–3378) DOI:10.1167/iovs.07-1247

Cataract surgery is one of the most common and successfully performed surgical procedures used to control vision loss in the United States, with more than 1 million surgeries performed each year.1 Its success relies on accurate preoperative biometry of curvature and intraocular distances, particularly axial length,2 to calculate the appropriate intraocular lens (IOL) power with the appropriate formula, (e.g., Holladay II, Sanders-Retzlaff-Kraff [SRK] II, SRK/T, and Hoffer Q).3–14 Opti-
unable to evaluate or exclude subjects with dry eye or tear film irregularities.

Used in the study were two hydrophilic soft lenses—a low- and a high-water-content polymer lens—that have equal refractive power (−0.50 D), diameter (14.0 mm), and base curve (8.7 mm). The two lenses had a different manufacturer, polymer composition, index of refraction, and central thickness. The lenses tested were the SofLens38 (polymacon 62%, water content, 38%; refractive index, 1.43; approximate center thickness, 0.035 mm; Bausch & Lomb, Rochester, NY) and the Acuvue2 (Etafilcon A, water content, 58%; refractive index, 1.40; approximate center thickness, 0.119 mm; Johnson & Johnson, New Brunswick, NJ).

**Optical Biometry**

Three series of optical biometry measurements were performed on each subject during one session with the IOLMaster with software version 3.01 (Carl Zeiss Meditec Inc., Dublin, CA) and an optical coherence tomographer (OCT; model OCT-1, Carl Zeiss Meditec AG, Oberkochen, Germany), after autorefraction (Allergan Humphrey Automatic Refractor 585; Allergan, Irvine, CA) prescreening. Three OCT central corneal thickness, 10 IOLMaster axial lengths, and 3 IOLMaster keratometry scans were collected on each subject’s naked right eye and were repeated in the presence of each soft contact lens in one continuous session. Experienced contact lens wearers inserted and removed each contact lens; otherwise, insertion and removal were performed by the clinical investigator who checked each subject’s cornea after the session. No corneal disturbances were reported during or after the study.

Measurements were collected first on the naked eye with no contact lens, repeated with the SofLens38 (CL1) and then the Acuvue2 (CL2) lens. One experienced investigator performed all ocular examinations except OCT for each condition. A second skilled investigator performed the OCT measurements. Three central corneal OCT line scans composed of multiple A-scans were used to determine the in situ contact lens thickness with precorneal tear film as described by Muscat et al.22 and Wang et al.23 (Fig. 1). The IOLMaster was then used to measure axial length and keratometry, including the corneal radius of the two principle meridians, the corneal power, the axes and the astigmatic difference. Each keratometry measurement is the mean value of five individual measurements acquired within 0.5 seconds. The radius of curvature was converted to diopters by using a 1.3375 refractive index. Each K reading was calculated as \( (K_1 + K_2)/2 \), corresponding to the principal meridians and recorded in diopters K.

A minimum of 10 minutes elapsed between the contact lens insertion and the first OCT scan. The delay allowed any contact lens ‘tightening’ to the cornea or edema, which typically stabilizes within the first few minutes of wear, to occur.24 Each session proceeded at a similar rate and lasted 73±14 minutes. On average, 12.5±2.4 minutes elapsed between CL1 insertion and the first OCT scan, and 19.2±3.6 minutes elapsed between the first OCT scan and the first IOLMaster scan. CL2 followed at 11.9±2.4 and 18.8±3.4 minutes, respectively.

The IOLMaster measures the axial length optically using dual-beam infrared PCI. The system calculates the axial length from the reflected interference signal as the distance between the tear film and the retinal pigment epithelium of the eye. The keratometry calculation is based on the reflection of six concentric dots focused on the surface of the cornea. The measurement feasibility depends on the signal-to-noise ratio of the reflected signal and the dot symmetry. A low signal can occur in eyes with a corneal irregularity, corneal scarring, severe dry eye, very high ametropia (>6 D), and in early post-PRK eyes.

**Figure 1.** Contact lens thicknesses were determined from anterior OCT multiple-line B-scans of the central cornea region (left). (A) OCT scans of a normal cornea with no contact lens. The mean central corneal thickness is the distance between peaks \( \alpha \) and \( \beta \). The reflectance peaks from the averaged A-scans were used to determine the cornea and lens thicknesses. The relevant peaks were identified and labeled in these scans (right): \( \alpha \), air-to-precorneal tear film interface; \( \beta \), air-to-prelens tear film interface; \( \gamma \), posterior contact lens-to-post-lens tear film interface; and \( * \), posterior cornea-to-aqueous interface. Similar OCT scans of a normal cornea with (B) CL1 and (C) CL2 are shown. The mean central contact lens thickness is the distance between peaks \( \beta \) and \( \gamma \).
The reproducibility and reliability of the PCI difference technique used to measure accurate axial lengths was evaluated for each lens. The repeatability and agreement between the lens and no-lens mean K-reading measurements were evaluated by two-way, repeated-measures ANOVA (P < 0.05). Regression analysis was used to assess potential systematic errors correlating to the base biometry.

### RESULTS

#### Axial Length Measurement

Each soft contact lens increased the axial length in a repeatable manner and was reliably detected by PCI (P < 0.0001). The distribution across subjects is shown in Figure 2. The group mean PCI axial length measured was 24.77 ± 1.04 mm (range, 22.00–26.48) for the no-lens condition, 24.83 ± 1.04 mm (range, 22.07–26.54) with SoLens38, and 24.90 ± 1.04 mm (range, 22.14–26.60) with Acuvue2. The mean change in axial length associated with each lens was 59 ± 10 μm (range, 41–74) with SoLens38 and 134 ± 13 μm (range, 111–155) with Acuvue2.

Neither soft contact lens significantly increased the variability of the PCI-based IOLMaster axial length measurement. The variances in the group mean PCI-based axial length measurements were 20 ± 7 μm (range, 10–38) with no lens, 24 ± 10 μm (range, 14–52) with SoLens38 and 23 ± 8 μm (range, 13–47) with Acuvue2. Although the mean SD in axial length measurement increased slightly, the variances between the no-lens and both lens conditions were not significantly different (P = 0.18). The two lenses also performed similarly, in that there was no statistically significant difference between the variances of each mean axial length measurement (P = 0.41).

Furthermore, the change in axial length measured by PCI corresponded to the OCT-determined contact lens thickness for each lens (Table 1). Subtraction of the higher-resolution OCT thickness measurements of the lens versus no-lens condition provided detectable contact lens thicknesses (P < 0.0001). The mean OCT differences corresponding to the soft lens and precorneal tear film thicknesses (Fig. 2) were 61 ± 6 μm (range, 47–72) for SoLens38 and 136 ± 3 μm (range, 129–143) for Acuvue2. The axial length differences from PCI were comparable to the corneal thickness differences from OCT for each lens (Fig. 3). For the SoLens38 lens condition, the measured PCI axial length difference was 59 ± 10 μm compared with the OCT corneal thickness difference of 61 ± 6 μm. For the Acuvue2 lens condition, the PCI axial length difference was 134 ± 13 μm, compared with the OCT corneal thickness difference of 136 ± 3 μm (range, 129–143).

![Figure 2](image.png)

**Figure 2.** The distribution across subjects of the change in axial length corresponding to each soft contact lens is presented for CL1 (SoLens38) and CL2 (Acuvue2). The variability in IOLMaster measured axial length differences was greater between the two −0.5-D lenses than between subjects. The group-averaged mean axial length differences were 59 ± 10 μm for CL1 and 134 ± 13 μm for CL2, corresponding to increases in the base axial length of 0.24% and 0.54%, respectively.

### Table 1. Axial Length and Contact Lens Thickness Measurements

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean AL</th>
<th>Mean SD</th>
<th>Mean CL Thickness, OCT Diff.</th>
<th>AL Diff.-OCT Diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>No CL</td>
<td>24.77 ± 1.04*</td>
<td>20 ± 7†‡</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Range</td>
<td>22.00–26.48†</td>
<td>10–38†‡</td>
<td>61 ± 6††</td>
<td>−2 ± 10††</td>
</tr>
<tr>
<td>+CL1</td>
<td>24.86 ± 1.04</td>
<td>24 ± 10</td>
<td>41–74††</td>
<td>47–72††</td>
</tr>
<tr>
<td>+CL2</td>
<td>22.07–26.54</td>
<td>14–52</td>
<td>134 ± 13</td>
<td>129–143</td>
</tr>
<tr>
<td>Range</td>
<td>22.90 ± 1.04</td>
<td>23 ± 8</td>
<td>136 ± 3</td>
<td>−2 ± 13</td>
</tr>
</tbody>
</table>

IOLMaster group mean axial length (AL), standard deviations (N = 10 consecutive measurements), and AL differences are presented for 20 subjects for the conditions of no contact lens (No CL), with SoLens38 (+CL1), and with Acuvue2 (+CL2). The mean contact lens thicknesses for each lens condition corresponding to the corneal OCT difference measurements are also presented. The mean OCT measurements for CL1 and CL2 were 2 μm larger than the corresponding IOLMaster AL measurements. Although the variability was slightly greater with CL2, the two techniques detected statistically similar changes in thickness associated with either lens (P = 0.995).

* In mm.
† In μm.
‡ Within subjects.
thickness difference of 136 ± 3 μm. The variance introduced by use of either lens was similar (P = 0.995), when the axial length and corneal thickness difference measurements were compared (P = 0.50 for SoLenses38 and P = 0.56 for Acuvue2).

The PCI axial length differences for each lens were similar to the OCT contact lens thickness measurements, in a one-way ANOVA comparison (P = 0.50 for SoLenses38 and P = 0.56 for Acuvue2, with the Levene test for homogeneity of variance P = 0.02 for SoLenses38 and P = 0.001 for Acuvue2). These results demonstrate the accuracy of using either the IOLMaster or OCT contact lens thickness to determine the actual axial length when a soft lens is applied.

Table 2. Central Corneal K-reading Measurements

| Condition   | Mean K-reading | Mean SD      | Mean K-reading Difference‡ | Adjusted Mean K Difference§ | Adjusted Mean K Difference||
|-------------|----------------|-------------|---------------------------|-----------------------------|-----------------------------|
| No CL       | 43.48 ± 1.69*  | 0.04 ± 0.02† | —                         | —                           | —                           |
| Range       | 41.21–47.12    | 0.00–0.11‡   | −0.40 ± 0.12‡             | 0.10 ± 0.12§                | 0.00 ± 0.12§                |
| +CL1        | 43.08 ± 1.66   | 0.09 ± 0.09  | −0.57–−0.20*              | −0.07–−0.30†                | −0.17–−0.20†                |
| Range       | 41.00–46.72    | 0.02–0.41    | −0.69 ± 0.19              | −0.19 ± 0.19                | 0.00 ± 0.19                 |
| +CL2        | 42.79 ± 1.57   | 0.09 ± 0.06  | −1.04–−0.30               | −0.54–−0.20                 | −0.35–−0.39                 |
| Range       | 40.80–46.08    | 0.02–0.28    | —                         | —                           | —                           |

IOLMaster group mean central corneal K-reading and standard deviations of 20 subjects are presented for the following conditions: with no contact lens (No CL), with SoLenses38 (+CL1), and with Acuvue2 (+CL2). The mean K-reading differences correspond to each low-power contact lens effect and include curvature, fit, and tear film irregularities. The estimated lens contribution, subtracting the thin, soft contact lens power (−0.5 D) of each lens, shifts the K-readings to within 0.5 D of the actual keratometry. The change in K reading is lens specific (Fig. 6), and so a more accurate adjustment is obtained by subtracting the mean K-reading differences associated with each lens, as shown.

* In diopters.
† Within subjects.
‡ Includes the low-power contact lens contribution.
§ Adjusted for estimated contact lens curvature by subtracting the manufacturer’s lens power.
∥ Adjusted by subtracting the experimentally-determined lens-specific group mean K-reading difference.

K-Reading Measurement

The mean K reading measured ± for each condition across the group based on the individual means was 43.48 ± 1.69 D (range, 41.21–47.12) for the no-lens condition, 43.08 ± 1.66 D (range, 41.00–46.72) with SoLenses38, and 42.79 ± 1.57 D (range, 40.80–46.08) with Acuvue2 (Table 2). These mean K readings are significantly different (P < 0.0001). The distribution of K-reading differences across subjects is shown in Figure 4. The effect of each lens was assessed by comparing the lens versus no-lens mean K-reading differences. SoLenses38 corresponded to a mean K-reading difference of −0.40 ± 0.12 D and Acuvue2 to a mean K-reading difference of −0.69 ± 0.19 D. These values include the curvature and lens effects associated with each −0.5 D contact lens. The lens effect should be minimal in a low-power lens. If one approximates the lens effect using the lens power, the magnitude of the effective differences adjusts to 0.10 ± 0.12 D for SoLenses38 and −0.19 ± 0.19 D for Acuvue2. The adjusted mean K readings were distinct from those with no lens (P = 0.0011 for SoLenses38 and P = 0.0002 for Acuvue2); however, these differences may be clinically acceptable, considering that the variances were within 0.5 D and within the minimum power tolerance allowed for pseudophakic IOLs.37 Accuracy improved when the K readings were adjusted by the experimentally determined, lens-specified mean K differences (Fig. 5).

The mean K-reading measurement SD with no lens was 0.04 ± 0.02 D (range, 0.00–0.11), 0.09 ± 0.09 (range, 0.02–0.41) with SoLenses38, and 0.09 ± 0.06 D (range, 0.02–0.28) with Acuvue2 (Table 2). The mean K-reading variance increased slightly with each lens; however, the increase was small (0.05 D) and similar for each lens (P = 0.84).

The changes in mean K reading are lens specific (Fig. 6) and correlate with the measured axial length differences (P < 0.01). To test whether the subject’s base corneal thickness, axial length, and K reading influenced the technique, regression analyses were performed (Figs. 7, 8, 9). A statistically significant error is observed only in the CL2-difference K readings, compared with both base axial length and corneal curvature.

Determining the Mean Absolute Error in the IOL Power Formula

IOL power formulae are continually being developed to improve predictive accuracy.5,7,8,28–30 However, to provide a
basic example of the influence of uncorrected errors in axial length and K reading with either lens, we applied the SRK II equation,\textsuperscript{4,31} where the dioptric lens power equals $A_{\text{constant}}/H^{1.1002}2.5/H^{1.1003}0.9/H^{1.1002}$.

According to the formula, the axial length error has a proportionally greater influence on the predicted postsurgical refractive power than does the K-reading error (ratio, $2.5:0.9$ or $2.78:1$).\textsuperscript{32} The change in axial length due to the added soft contact lens is expected to be a small percentage, or $50$ to $150\mu m$. For reference, an error in axial length of $100\mu m$ would result in a refractive error of $0.28 D$.\textsuperscript{2} For our emmetropic to moderately myopic eyes, the SD in IOLMaster-measured K reading increased by $0.05 D$, and axial length did not significantly increase in the presence of a soft contact lens. As shown in this study, one can determine the change in axial length to within $0.013 mm$ with the IOLMaster and $0.006 mm$ with the corneal OCT. Assuming the maximum uncertainties in axial length and K reading attributable to the technique, one can expect an error of $\pm 0.13 D$ for SofLens38 and $\pm 0.20 D$ for Acuvue2 when applying this formula. These errors contribute an uncertainty of $\pm 0.5 D$ to the power calculation. IOLs are currently calibrated to correct eyes within $\pm 0.5 D$; therefore, the error is considered to be clinically acceptable.

**DISCUSSION**

Methods incorporating hard contact lenses have been used to measure the postoperative corneal power and biometry in eyes with regular corneal surfaces, in such conditions as keratoconus or after refractive surgery.\textsuperscript{33–39} The soft contact lens method is not intended for these cases; instead, it is intended for cases with irregular surfaces and irregular astigmatism (i.e., allowing measurement in situations in which optical biometry cannot be accurately measured otherwise). With a rigid lens, the corneal curvature will be measured as the front curvature of the lens, irrespective of the underlying corneal curvature. Our hypothesis was that the curvature of the cornea with a low-power soft contact lens would be predictably related to the underlying corneal curvature.

To test the efficacy of soft contact lens–assisted IOL power measurements, we performed a prospective study to analyze the effect of two similar soft contact lenses on PCI biometry. Two $-0.5-D$ soft contact lenses were evaluated for repeatability and reliability, to estimate the corneal surface curvature and axial length. The repeatability and accuracy of this method has not been evaluated before and was evaluated on normal eyes with reference to contact lens–free biometry.
These data support accurate use of IOLMaster measurements in the presence of soft contact lenses similar to the Soft Lens38 and Acuvue2. The variability and accuracy of axial length measurements did not significantly change with either lens. The variability in K reading increased slightly (0.05 D) in the presence of either lens and could be accurately adjusted to subtract either lens contribution. The Acuvue2 K-reading difference was sensitive to base axial length and K reading, possibly reflecting a change in fit across the sample. These K-reading differences were greater for shorter base axial lengths and steeper base K readings. Rates of change of $-0.11$ D/mm between 26.5- and 22-mm base axial length and $0.08$ D per diopter base K reading between 41 and 47 D were measured. The Acuvue2 K-reading differences could be compensated accordingly; otherwise, a maximum K-reading difference of $-0.31$ D can be expected, as observed in the extreme cases encountered. The SoftLens38 did not show this dependence and may yield more accurate measurements when applied, irrespective of the base biometry.

Differences in manufacturing method and material composition may explain these results. The SoftLens38 and Acuvue2 are manufactured by different processes: The SoftLens38 is cast-molded and the Acuvue2 is stabilized soft-molded. Also, different cast-molded lenses can perform differently.\textsuperscript{40} Other differences include the water content and thickness, which could influence the rigidity of the lens.

IOLMaster axial length measurements in the presence of either lens were repeatable. The change in axial length was detectable and corresponded to the change in central corneal thickness measured directly by corneal OCT. Therefore, the thickness added by either contact lens could be reliably subtracted from the axial length measurement using either PCI or

![Figure 7](image)

**Figure 7.** In the first of three tests for systematic errors in the technique corresponding to the base biometry, regression analysis was performed on the IOLMaster mean change in (A) axial length, (B) the OCT mean contact lens thickness, and (C) the IOLMaster mean (unadjusted) K-reading differences for CL1 and CL2, as a function of the mean base central corneal thickness. No significant correlations were identified ($P > 0.05$).

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![Figure 8](image)

**Figure 8.** In the second of three tests for systematic errors in the technique corresponding to the base biometry, regression analysis was performed on the IOLMaster mean change in (A) axial length and (B) (unadjusted) K reading for CL1 and CL2, as a function of the mean base axial length. Only the mean K-reading difference measurement for CL2 had a significant linear correlation ($R^2 = 0.56$, $P < 0.01$), indicating a negative error in the measured K-reading differences that increased as a function of decreasing base axial lengths. The effect corresponds to an error of $-0.14$ D/mm decrease in base axial length for CL2.
OCT subtraction methods. For clinical application, the effect of these contact lens thicknesses on the axial length is not significant; however, it can be accurately estimated using either subtraction method. The K-reading adjustments were lens specific; however, they had similar variances. These lens contributions can be estimated by the lens power or accurately specified by using the experimentally determined, lens-associated mean K-reading differences.

Optical biometry and keratometry measurements in eyes with corneal irregularities are a challenge. Limitations of using this method to measure diseased eyes may include variation introduced to the PCI axial length measurement by extreme stromal edema or severe cataract. In mild-to-moderate cases of Fuchs' dystrophy, for example, the corneal surface is generally smooth, and keratometry can easily be performed. A soft contact lens may not improve biometry in these cases, in which corneal irregularities are a challenge. Limitations of using the soft lens method in eyes with coexisting cataract and corneal disease is warranted.

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References


