Aspheric Intraocular Lens Selection Based on Corneal Wavefront

Mark Packer, MD, FACS; I. Howard Fine, MD; Richard S. Hoffman, MD

ABSTRACT

PURPOSE: To determine the feasibility of selectively targeting zero total postoperative spherical aberration by selecting the best fit aspheric intraocular lens (IOL) based on preoperative topographically derived corneal spherical aberration.

METHODS: Candidates for cataract surgery were offered selection of aspheric IOLs based on corneal spherical aberration. The target postoperative total wavefront spherical aberration Z4,0 was set at zero. Corneal topographic spherical aberration Z4,0 was measured at the 6-mm optical zone, and one of three aspheric IOLs was chosen so the arithmetic sum of the corneal spherical aberration and pseudophakic spherical aberration came closest to zero. Postoperatively, total ocular wavefront was measured and statistical analysis performed to ascertain the accuracy of customized aspheric IOL selection.

RESULTS: Thirty eyes of 18 patients were available for analysis. The SofPort Advanced Optics (Bausch & Lomb) lens was implanted in 1 eye, the AcrySof IQ (Alcon Laboratories Inc) in 11 eyes, and the Tecnis Z9000 or Z9002 (Advanced Medical Optics [AMO]) in 18 eyes. Total postoperative ocular spherical aberration for the entire population measured 0.013 ± 0.072 µm (SofPort: 0.025 µm; AcrySof IQ: 0.010 ± 0.053 µm; and Tecnis: −0.015 ± 0.052 µm [P = .22]). For the entire population, mean absolute predictive error measured 0.058 ± 0.056 µm (SofPort: 0.040 µm; AcrySof IQ: 0.052 ± 0.040 µm; and Tecnis: 0.063 ± 0.066 µm [P = .63]).

CONCLUSIONS: Customized selection of aspheric IOLs based on corneal wavefront is feasible and produces favorable results compared with studies of unselected patient populations implanted with aspheric IOLs. [J Refract Surg. 2009;25:12-20.]
The AcrySof IQ shares ultraviolet and blue light filtering chromophores found in the single-piece acrylic AcrySof Natural IOL (SN60AT, Alcon). The special feature of the IQ IOL is the posterior aspheric surface, which is designed to reduce spherical aberration by addressing the effects of over-refraction at the periphery. It adds $-0.20$ µm of spherical aberration to the eye at the 6-mm optical zone. The SofPort Advanced Optics (LI61AO) IOL is an aspheric IOL that has been specifically designed with zero spherical aberration so it will not contribute to any pre-existing higher order aberrations.

Multiple peer-reviewed, prospective, randomized, scientific publications have demonstrated reduction or elimination of spherical aberration with the Tecnis modified prolate IOL when compared with a variety of spherical IOLs.\textsuperscript{4-13} Data show that mean spherical aberration in eyes implanted with the Tecnis IOL is, in the words approved by the FDA, “not different from zero.” Studies have also documented superior functional vision with the Tecnis IOL. Patients in the FDA-monitored, randomized, double-masked night driving simulation study of the Tecnis IOL performed functionally better in 20 of 24 driving conditions (and statistically better in 10 conditions) when using best spectacle-corrected visual acuity (BSCVA) with the eye implanted with the Tecnis IOL, as compared to BSCVA with the eye implanted with the AcrySof spherical IOL.\textsuperscript{2} Data from the night driving simulation showed a significant correlation between reduction of spherical aberration and detection distance for the pedestrian target under rural conditions with glare (the most difficult target to discern).

More recently, peer-reviewed published clinical studies have also supported reduction of spherical aberration and superior functional vision with the AcrySof IQ when compared with spherical IOLs.\textsuperscript{14-17} In fact, the optical advantages of aspheric IOL technology have become fairly well accepted, although some controversy remains in the area of functional benefit as it relates to pupil size, IOL decentration, depth of focus, and customization.\textsuperscript{18} Some studies have shown little or no benefit of aspheric IOLs with smaller pupils,\textsuperscript{12,13} whereas one laboratory study showed that the SofPort AO provides better optical quality than a negatively aspheric or spherical IOL under conditions of significant decentration.\textsuperscript{19} One study has shown diminished distance-corrected near visual acuity (a surrogate measure for depth of focus) with the AcrySof IQ aspheric IOL compared to the AcrySof SN60AT spherical IOL.\textsuperscript{17}

Regarding customization of the aspheric correction, it has been suggested that achieving zero total spherical aberration postoperatively provides the best quality of vision. Piers et al\textsuperscript{20} utilized an adaptive optics simulator to assess letter acuity and contrast sensitivity for two different values of spherical aberration. The first condition was the average amount of spherical aberration measured in pseudophakic patients with spherical IOLs. The second condition represented the complete correction of the individual’s spherical aberration (Z4,0=0). The researchers found an average improvement in visual acuity associated with correction of spherical aberration of 10% and 38% measured in white and green light, respectively. Similarly, average contrast sensitivity measurements improved 32% and 57% in white and green light, respectively. When spherical aberration was corrected, visual performance was as good as or better than the normal spherical aberration for defocus as large as $\pm 1.00$ diopters (D). Therefore, these researchers concluded that completely correcting ocular spherical aberration improves spatial vision in the best focus position without compromising the subjective tolerance to defocus.

### TABLE 1

<table>
<thead>
<tr>
<th>Aspheric Intraocular Lenses Used in the Present Study</th>
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<tr>
<td><strong>Intraocular Lenses</strong></td>
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<tr>
<td><strong>Manufacturer</strong></td>
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<tr>
<td><strong>Code number</strong></td>
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<tr>
<td><strong>Design</strong></td>
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<td><strong>Optic (mm)</strong></td>
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<td><strong>Material</strong></td>
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<tr>
<td><strong>Chromophore</strong></td>
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<td><strong>Spherical aberration (µm)</strong></td>
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On the other hand, it has alternatively been suggested that providing $Z(4,0)=+0.1 \, \mu m$ of postoperative spherical aberration represents a better choice. This line of reasoning originated from a study demonstrating that 35 young patients with uncorrected visual acuity of 20/15 or better had a mean total spherical aberration of $Z(4,0)=+0.110\pm0.077 \, \mu m$. However, there is no logical basis to infer that spherical aberration is responsible for supernormal visual acuity. In fact, the authors of this study concluded that, “The amount of ocular higher order aberrations in eyes with natural supernormal vision is not negligible, and is comparable to the reported amount of higher order aberrations in myopic eyes.” This conclusion is born out by a study performed by Wang and Koch, demonstrating mean total spherical aberration of $Z(4,0)=+0.128\pm0.074 \, \mu m$ in a series of 532 eyes of 306 patients presenting for refractive surgery. Nevertheless, Beiko used the Easygraph corneal topographer (Oculus, Lynnwood, Wash) to select patients with corneal spherical aberration of $+0.37 \, \mu m$, thus targeting a postoperative total ocular spherical aberration of $+0.10 \, \mu m$ following implantation of the Tecnis IOL with $+0.27 \, \mu m$ (the Easygraph includes an optional software package that provides Zernike analysis). The selected patient group demonstrated significantly better contrast sensitivity than an unselected group of control patients under mesopic and photopic conditions.

Recently, Beiko et al presented data from a series of 696 eyes confirming the mean corneal spherical aberration of $+0.27 \, \mu m$ used in the design of the Tecnis IOL. They found a wide standard deviation of $0.089 \, \mu m$ (range: $+0.041$ to $+0.632 \, \mu m$) and significantly different mean corneal spherical aberrations in men and women. In some cases, the corneal spherical aberration differed significantly between fellow eyes. The authors concluded that “individuals should be measured to determine their unique value when considering correction of this aberration.” In addition, they noted that keratometry and the corneal Q value do not correlate well with spherical aberration; therefore, corneal spherical aberration must be measured directly with a topographer.

The current study was undertaken to determine the feasibility of selectively targeting zero total postoperative spherical aberration by selecting the best fit aspheric IOL based on preoperative topographically derived corneal spherical aberration (Fig 1).

**PATIENTS AND METHODS**

Candidates for unilateral or bilateral cataract surgery who did not desire presbyopia-correcting IOLs were offered customized selection of aspheric lenses. Patients were excluded with history of keratorefractive surgery, ocular pathology judged to limit potential visual acuity 20/30 or worse, or sufficient corneal astigmatism to indicate peripheral corneal relaxing incisions. Informed consent for cataract surgery was obtained from all patients.
Preoperative evaluation included complete ophthalmologic examination, including manifest refraction, BSCVA, and brightness acuity testing if indicated. In some cases, a visual function questionnaire was administered to help ascertain if cataract surgery was indicated. Axial length measurement, keratometry, anterior chamber depth, and corneal white-to-white measurements were obtained with the IOLMaster (Carl Zeiss Meditec Inc, Dublin, Calif). Preoperative corneal topographic spherical aberration (Z4,0) was measured at the 6-mm optical zone (iTrace; Tracey Technologies, Houston, Tex) (Fig 2).

Intraocular lens power calculation was performed with the Holladay IOL Consultant using the Holladay II formula (Jack Holladay, Bellaire, Tex). An aspheric IOL was selected for implantation in each eye based on preoperative corneal spherical aberration and the labeled IOL spherical aberration, such that the arithmetic sum of these two values was closest to zero. Thus, for corneal spherical aberration $<+0.1 \mu m$, the SofPort was selected; for corneal spherical aberration $>+0.1 \mu m$ but $<+0.235 \mu m$, the AcrySof IQ was selected; and for corneal spherical aberration $>+0.235 \mu m$, the Tecnis Z9000 or Tecnis Z9002 was selected.

Patients returned for evaluation at 4 to 6 weeks postoperatively, which included manifest refraction, BSCVA, pupillometry, and dilated wavefront aberrometry (WASCA; AMO WaveFront Sciences LLC, Albuquerque, NM). The measured total ocular spherical aberration Z4,0 for a maximum 6-mm pupil size was compared with the predicted value given mathematically by the sum of the preoperative corneal spherical aberration and the labeled IOL spherical aberration.

RESULTS

Data from 30 eyes of 18 consecutive patients (9 men and 9 women) were available for analysis. Mean patient age was 72.8±6.2 years (range: 62 to 86 years). Preoperative biometric data for all patients are described in Table 2.

Mean preoperative corneal spherical aberration measured at the 6-mm optical zone for the entire population was $+0.26\pm0.089 \mu m$. One eye had Z4,0 $<+0.1 \mu m$; therefore, was selected to receive the SofPort IOL. The corneal spherical aberration of this eye measured $+0.065 \mu m$. Eleven eyes had Z4,0 $>+0.1 \mu m$ but
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TABLE 2
Mean Preoperative Biometric Data for 30 Eyes Offered Customized Selection of Aspheric IOLs

<table>
<thead>
<tr>
<th>Mean Measurement (Range)</th>
<th>No. of Eyes</th>
</tr>
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<tbody>
<tr>
<td>Spherical equivalent refraction (D)</td>
<td>20/31 (20/20 to 20/70)</td>
</tr>
<tr>
<td>Snellen best spectacle-corrected visual acuity</td>
<td>20/20 (20/20 to 20/70)</td>
</tr>
<tr>
<td>Average keratometry (D)</td>
<td>43.35±2.10 (39.76 to 47.68)</td>
</tr>
<tr>
<td>Axial length (mm)</td>
<td>23.55±1.29 (20.64 to 25.39)</td>
</tr>
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Figure 3. Frequency distribution of corneal topographic wavefront spherical aberration Z4,0 in the study population (mean: +0.26±0.089 μm).

<+0.235 μm; therefore, were selected to receive the AcrySof IQ. The mean corneal spherical aberration of this group measured +0.18±0.037 μm. Eighteen eyes had corneal spherical aberration >+0.235 μm; therefore, received the Tecnis IOL. The mean corneal spherical aberration of this group measured +0.31±0.063 μm. The frequency distribution of preoperative corneal spherical aberration is shown in Figure 3.

All patients underwent uneventful phacoemulsification and IOL implantation by one surgeon (M.P.) utilizing a biaxial microincision technique.25 The capsulorrhexis diameter was intentionally sized at approximately 4.5 to 5.0 mm in all cases to facilitate the “shrink wrap effect” of the IOL for long-term prevention of posterior capsular opacification and maintenance of stable centration (Fig 4).26 Of the 12 patients implanted bilaterally, 10 received the same IOL in both eyes.

Postoperative BSCVA measured 20/20 or better in 27 of 30 eyes, 20/25 in 2 eyes, and 20/30 in 1 eye. Mean spherical equivalent refraction measured −0.32±0.54 D; 93.3% of eyes were within ±0.50 D of the targeted postoperative refraction. Mean postoperative cylinder was 0.375; no eye had >0.75 D of refractive astigmatism. Mean postoperative mesopic pupil size measured 3.58±0.78 mm. No significant tilt or decentration >0.25 mm of any IOL as measured by Guyton’s method was noted.27,28

Total postoperative ocular spherical aberration for the entire population measured −0.013±0.072 μm. Total ocular spherical aberration for the eye implanted with the SofPort IOL measured +0.025 μm. This single eye was excluded from further comparative statistical analysis but included in the descriptive statistics for the entire population. For eyes implanted with the AcrySof IQ, the mean total postoperative ocular spherical aberration measured +0.010±0.053 μm. For the eyes implanted with the Tecnis IOL, mean total postoperative ocular spherical aberration measured −0.015±0.052 μm. No statistically significant difference was noted between the postoperative ocular spherical aberration of the AcrySof IQ group and the Tecnis group (two-sample t test assuming equal variances, P=.22).

Examination of the difference between the predicted and measured postoperative spherical aberration for the entire group shows that the mean absolute error measured 0.058±0.056 μm. For eyes implanted with the AcrySof IQ, mean absolute error measured 0.052±0.040 μm. For eyes implanted with the Tecnis, mean absolute error measured 0.063±0.066 μm. A
two-sample \( t \) test assuming equal variances revealed no statistically significant difference between the mean absolute errors for the AcrySof IQ and Tecnis eyes \( (P=.63) \). Figure 5 shows a scatterplot of predicted versus measured \( Z_{4,0} \) for all eyes. As expected from the values and standard deviations for mean absolute error, almost all points lie within 0.10 \( \mu \)m of zero, and approximately half the points lie within 0.050 \( \mu \)m of zero. Figure 6 demonstrates the relationship of preoperative corneal spherical aberration and postoperative total spherical aberration with reference to the selected aspheric IOLs.

**DISCUSSION**

The value of customizing any refractive or wavefront parameter can only reside in enhanced outcomes. On average for all eyes, the customization procedure outlined here achieved mean total ocular spherical aberration of \(-0.013\pm0.072 \mu\)m; 93.3\% of eyes achieved total ocular spherical aberration of \(<\pm0.10 \mu\)m.

Other investigators have examined postoperative spherical aberration without selection of patients based on preoperative corneal measurements. For example, Padmanabhan et al\(^{29}\) found that mean spherical aberration was statistically significantly lower in eyes with a Tecnis Z9000 IOL \((Z_{4,0}=+0.07\pm0.12 \mu\)m) compared with eyes with an Acrysof MA60BM IOL \((Z_{4,0}=+0.29\pm0.20 \mu\)m, \(P<.001\)) and with eyes with a Sensar Optic Edge AR40e IOL \((\text{AMO}) \((Z_{4,0}=+0.20\pm0.09 \mu\)m, \(P=.002\)). Denoyer et al\(^{10}\) found that spherical aberration was lower in patients with the Tecnis IOL \((\text{mean } Z_{4,0}=+0.03 \pm 0.06 \mu\)m). Kasper et al\(^{13}\) reported median \( Z_{4,0}=+0.017 \mu\)m for eyes with the Tecnis IOL. Bellucci et al\(^{31}\) found that for a 4-mm optical zone, ocular spherical aberration was \(+0.0054\pm0.0172 \mu\)m root-mean-square (RMS) in eyes implanted with the Tecnis lens, and was \(+0.0562 \text{ to } +0.0974 \mu\)m RMS in eyes implanted with four other conventional IOLs. Awwad et al\(^{14}\) reported SN60WF-implanted eyes had less mean absolute spherical aberration than SN60AT eyes, both at 4-mm \((+0.04\pm0.03 \text{ vs } +0.11\pm0.03 \mu\)m RMS, \(P<.0001\)) and 6-mm pupils \((+0.09\pm0.04 \text{ vs } +0.43\pm0.12 \mu\)m RMS, \(P<.0001\)). Rocha et al\(^{16,17}\) found mean spherical aberration of \(+0.03\pm0.05 \mu\)m in their AcrySof IQ groups in two separate publications. Caporossi et al\(^{12}\) found that mean total spherical aberration with aspheric IOLs measured 0.05\pm0.06, 0.11\pm0.1, and 0.19\pm0.08 \mu\)m for the Tecnis Z9000, Acrysof IQ SN60WF, and Sofport L161AO, respectively, for a 5-mm pupil diameter. The results presented in the current study generally compare favorably
with the results in all other studies published in the peer-reviewed literature, although direct comparisons are difficult given various testing conditions, equipment, and variations in surgical technique.

Table 3 compares previously published reports and demonstrates relative superiority of the customized selection approach. Although Bellucci et al. reported a smaller magnitude of spherical aberration, it is critical to note that they used a 4-mm pupil size; Caporossi et al. reported ocular spherical aberration at a 5-mm pupil size. Kasper et al. did not report a standard deviation for postoperative spherical aberration. Other measurements in the various studies appear roughly comparable to the current study, although no attempt has been made to evaluate statistically significant differences in the sense of a meta-analysis.

As a feasibility study, the accuracy of our customization procedure is reflected in the difference between predicted and measured spherical aberration. The mean absolute error measured 0.058 ± 0.056 µm for all eyes. Several factors may influence these results and should be considered in our evaluation: effective postoperative pupil size, tilt or decentration of the IOL, and surgically induced spherical aberration.

The predicted postoperative spherical aberration is based on simple addition of the 6-mm preoperative cor-
neal Z4.0 value and the labeled 6-mm Z4.0 for each IOL. However, the aperture size of the postoperative wavefront measurement is limited by the lesser pupillary diameter following dilation and capsulorrhesis. These vary from case to case and will produce variations in the predictive accuracy of the customization process.

Additionally, an important limitation of the functional benefit of reduction of spherical aberration depends on the correction of defocus and astigmatism, ie, lower order aberrations. Furthermore, whereas a perfectly aspheric optical system may correct the spherical aberration of incoming parallel light rays, a near target will remain blurred because of defocus.

Regarding performance limitations of aspheric IOLs due to tilt and decentration, Piers et al\textsuperscript{33} recently demonstrated that customized correction of ocular wavefront aberrations with an IOL is relatively insensitive to as much as 0.8 mm decentration, 10° tilt, and 15° rotation. Fortunately, with continuous curvilinear capsulorrhesis and in-the-bag IOL fixation, few IOLs would be expected to fall outside of these criteria.\textsuperscript{34}

Some effect of surgery on the corneal spherical aberation should be expected to occur, which adds another variable to the system. In fact, Guirao et al\textsuperscript{35} determined that mean surgically induced spherical aberration following cataract extraction through a 3.5-mm clear corneal incision with implantation of a monofocal IOL for a 6-mm pupil calculated by ray-tracing from the corneal topography measures 0.03±0.17 µm (spherical aberration mean: preoperative +0.32±0.12 µm; postoperative +0.34±0.19 µm). However, with a mean absolute error of 0.058±0.056 µm for all eyes in this study, the degree of surgically induced spherical aberration could explain the majority of inaccuracy in the results. Postoperative topography was not included as an outcome measure in the present study and remains a topic for further research.

Another limitation of this feasibility study is the absence of psychometric testing or contrast sensitivity measurements to evaluate the functional results. Analysis of the functional impact of customized selection of aspheric IOLs must eventually rely on such data, which represent an important area for future study.

Along these lines, research in “just-noticeable differences” of refractive and wavefront errors indicates that 0.04 µm of RMS aberation should be considered the threshold.\textsuperscript{36} Although on a population average, the benefit of aspheric IOL selection based on corneal wavefront measurements may reside below this threshold, for a specific individual the difference may be noticeable. Customization is likely of particular importance for patients who had prior keratorefractive surgery such as LASIK. Selection of aspheric IOLs in this population remains a topic for future research.

REFERENCES


Aspheric IOL Selection by Corneal Wavefront/Packer et al


