Custom selection of aspheric intraocular lens in eyes with previous hyperopic corneal surgery

Li Wang, MD, PhD, Omar Shoukfeh, MD, Douglas D. Koch, MD

PURPOSE: To determine the optimum amount of spherical aberration in intra-ocular lenses (IOLs) to maximize optical quality in eyes with previous hyperopic corneal surgery.

SETTING: Cullen Eye Institute, Baylor College of Medicine, Houston, Texas.

DESIGN: Theoretical simulation study.

METHODS: The amount of spherical aberration in the IOL was varied to produce residual ocular spherical aberration ranging from −0.50 to +0.50 μm. With the use of the Zernike Tool Program, the polychromatic point-spread function with Stiles–Crawford effect was calculated for 6.0 mm and 4.0 mm pupils and defocus of 0.00 diopter (D), −0.50 D, and +0.50 D. The IOL spherical aberration at which maximum image quality was achieved was determined. Stepwise multiple regression analysis was performed to assess the predictors of optimum IOL spherical aberration.

RESULTS: Aspheric IOL implantation was simulated in 106 eyes of 80 patients; ages ranged from 40 to 59 years. With 0.00 D, −0.50 D, and +0.50 D defocus, respectively, the ranges of 25th to 75th percentiles of the optimum IOL spherical aberration were −0.12 to +0.20 μm, +0.10 to +0.42 μm, and −0.35 to −0.03 μm for the 6.0 mm pupil and −0.14 to +0.26 μm, +0.41 to +0.86 μm, and −0.74 to −0.24 μm for the 4.0 mm pupil. The amount of optimum IOL spherical aberration could be predicted on the basis of other higher-order aberrations (HOAs) of the cornea with multiple correlation coefficients up to 0.98.

CONCLUSIONS: The amount of IOL spherical aberration producing the best image quality in eyes with previous hyperopic corneal surgery varied widely and could be predicted on the basis of the full spectrum of corneal HOAs.

Financial Disclosure: Supported in part by an unrestricted grant from Research to Prevent Blindness, New York, New York. No author has a financial or proprietary interest in any material or method mentioned.

J Cataract Refract Surg 2015; 41:2652–2663 © 2015 ASCRS and ESCRS

Aspheric intraocular lenses (IOLs) have been designed to compensate for the inherent positive spherical aberration of the cornea.[1,2] In normal un-operated corneas, the corneal spherical aberration has been estimated to average +0.28 μm (for a 6.0 mm pupil).[3] In eyes after myopic corneal ablation, 4th-order spherical aberration has been shown to increase in the positive direction in microns.[4,5] In contrast, studies have shown that hyperopic corneal ablation induces a negative shift in 4th-order spherical aberration in millimeters, and the decrease is significantly correlated with increasing hyperopic correction.[6–10] To improve the optical quality produced by IOLs in eyes with previous corneal refractive surgery, custom selection of aspheric IOLs might be desirable.

In previous studies,[11,12] we found that the optimum IOL spherical aberration for a 6.0 mm pupil varied widely between eyes in normal eyes and eyes after myopic corneal surgery. The purposes of this study are, in eyes of patients who had hyperopic laser in situ keratomileusis (LASIK) or photorefractive keratectomy (PRK), to (1) estimate the optimum amount of ocular spherical aberration needed to optimize optical quality, (2) on the basis of these ocular values,

Published by Elsevier Inc.

http://dx.doi.org/10.1016/j.jcrs.2015.06.033
0886-3350

estimate the optimum amount of asphericity in an IOL to optimize visual quality, (3) determine the magnitude of differences in these calculations performed with the use of a 6.0 mm versus a 4.0 mm pupil, (4) determine the magnitude of differences if the IOL is selected on the basis of all higher-order aberrations (HOAs) versus corneal spherical aberration alone, and (5) provide formulas for the 6.0 mm and 4.0 mm pupils to predict the optimum IOL asphericity for this population, incorporating pertinent corneal higher-order aberrations up to the 6^{th} order. The goals were to aid clinical judgment and suggest future directions in IOL design.

PATIENTS AND METHODS

Patients

Institutional Review Board approval was obtained for this study. These patients underwent hyperopic LASIK or PRK by a single surgeon from July 2003 to December 2006 using the Star laser system (Abbott Medical Optics, Inc.). Of 106 eyes, 81 eyes had standard hyperopic LASIK, 7 eyes had wavefront-guided hyperopic LASIK, and 18 eyes had wavefront-guided hyperopic PRK (Customvue, Abbott Medical Optics, Inc.). Inclusion criteria were availability of follow-up at least 3 months after LASIK and 6 months after PRK and Atlas corneal topographic maps (Carl Zeiss, Inc.) with no missing data points within the central 6 mm zone. Retreated and near-goal eyes were excluded from the study.

Selection of Ocular Spherical Aberration that Produces Optimum Ocular Image Quality

The corneal topographic maps were recentered around the entrance pupil, and corneal wavefront aberrations were calculated on the basis of anterior corneal measurements from corneal topography with the use of VOL-CT software (Sarver and Associates, Inc.) with an anterior corneal index of refraction of 1.376 for the wavelength of 555 nm. Calculations were performed for 6 mm and 4 mm pupil sizes. In each eye, we simulated implantation of aspheric IOLs to produce residual spherical aberration ranging from −0.50 μm to +0.50 μm with 0.01 μm intervals. The remaining ocular wavefront aberrations resulted from those of the corneal surface and the aspheric IOLs. For the purposes of data display and analysis, eyes were grouped into optimum spherical aberration bins of 0.05 μm. For example, an optimum spherical aberration value of −0.01 μm falls between −0.025 μm to +0.025 μm and would be included in the 0.00 μm bin.

Submitted: April 6, 2015.
Final revision submitted: June 4, 2015.
Accepted: June 7, 2015.

From Cullen Eye Institute, Department of Ophthalmology, Baylor College of Medicine, Houston, Texas.

Corresponding author: Douglas D. Koch, MD, Department of Ophthalmology, Cullen Eye Institute, Baylor College of Medicine, 6565 Fannin St, NC-205, Houston, TX 77030, USA. E-mail: dkoch@bcm.edu.

The polychromatic point spread function (PSF) with Stiles–Crawford effect was calculated for the residual ocular HOAs with the use of the Zernike Tool Program (Abbott Medical Optics, Inc.).[13] This program uses 7 wavelengths (400 nm, 450 nm, 500 nm, 550 nm, 600 nm, 650 nm, and 700 nm) to represent the visible spectrum. The PSF from a single wavelength was calculated individually and weighted linearly in the imaging plane based on the retinal spectral response function.

Optical image quality was quantified on the basis of 2 parameters. The first was the modulation transfer function (MTF) volume up to 15 cycles per degree (cpd): this represents an integrated 3-dimensional volume under the MTF curve equivalent to 20/40 visual acuity. The second was the Strehl ratio, which represents a ratio of peak focal intensities in aberrated versus ideal PSF; a value of 1 exists in a perfect optical system and decreases with increasing aberrations.

Assuming full correction of 2nd-order astigmatism, the polychromatic PSF was calculated for the residual ocular HOAs with zero defocus and defocus of −0.50 D and +0.50 D. The spherical aberration value achieving maximum image quality was selected for each eye under each of the above parameters. For instance, if an eye had maximal Strehl ratio with a simulated spherical aberration of −0.10 μm, this would be considered optimum ocular spherical aberration for this eye with the use of this parameter.

Selection of Intra-ocular Lens Spherical Aberration that Produces Optimum Ocular Image Quality

By subtracting the original corneal spherical aberration from the spherical aberration that produces optimum ocular image quality, the optimum IOL spherical aberration was determined. For example, if an eye had a corneal spherical aberration of +0.27 μm and an optimum ocular spherical aberration of −0.10 μm, an IOL with spherical aberration of −0.37 μm would provide best optimum image quality, based on that parameter. For the 4 mm pupil calculations, we first calculated the optimum IOL spherical aberration for a 4 mm pupil, based on the optimum ocular spherical aberration at this pupil size, and then calculated the optimum IOL spherical aberration for a 6 mm zone that produced the required IOL spherical aberration for a 4 mm pupil; this enabled us to indicate the asphericity of the optimum IOL at the 6 mm zone, in accordance with the current method of labeling IOL asphericity. Therefore, unless indicated otherwise, the values for 4th-order corneal spherical aberration, ocular spherical aberration, and IOL spherical aberration that produce optimum ocular image quality are given at their magnitudes for the 6 mm pupil.

Difference in Optimum Intra-ocular Lens Spherical Aberration for 6 mm Pupil and 4-mm Pupil

We determined the magnitude of differences in optimum IOL spherical aberration required for a 6 mm versus a 4 mm pupil.

Optimum Intra-ocular Lens Spherical Aberration Based on all Corneal Aberrations versus Corneal 4th-Order Spherical Aberration

If the IOL spherical aberration was selected based on the corneal 4th-order spherical aberration by targeting for zero