CUSTOM OPTIMIZATION OF INTRAOCULAR LENS ASPHERICITY

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ABSTRACT

Purpose: To investigate the optimal amount of ocular spherical aberration (SA) in an intraocular lens (IOL) to maximize optical quality.

Methods: In 154 eyes of 94 patients aged 40 to 80 years, implantation of aspheric IOLs was simulated with different amounts of SA to produce residual ocular SA from -0.30 µm to +0.30 µm. Using the VOL-CT program (Sarver & Associates, Carbondale, Illinois), corneal wavefront aberrations up to 6th order were computed from corneal topographic elevation data (Humphrey Atlas, Carl Zeiss Meditec, Inc, Dublin, California). Using the ZernikeTool program (Advanced Medical Optics, Inc, Santa Ana, California), the polychromatic point spread function with Stiles-Crawford effect was calculated for the residual ocular higher-order aberrations (HOAs, 3rd to 6th order, 6-mm pupil), assuming fully corrected 2nd-order aberrations. Five parameters were used to quantify optical image quality, and we determined the residual ocular SA at which the maximal image quality was achieved for each eye. Stepwise multiple regression analysis was performed to assess the predictors for optimal SA of each eye.

Results: The optimal SA varied widely among eyes. Most eyes had best image quality with low amounts of negative SA. For modulation transfer function volume up to 15 cycles/degree, the amount of optimal SA could be predicted based on other HOAs of the cornea with coefficient of multiple determination (R^2) of 79%. Eight Zernike terms significantly contributed to the optimal SA in this model; the order of importance to optimal SA from most to least was: Z_6^0, Z_6^2, Z_4^2, Z_5^3, Z_6^4, Z_3^{-1}, Z_3^3, and Z_3^1. For the other 4 measures of visual quality, the coefficients of determination varied from 32% to 63%.

Conclusion: The amount of ocular SA producing best image quality varied widely among subjects and could be predicted based on corneal HOAs. Selection of an aspheric IOL should be customized according to the full spectrum of corneal HOAs and not 4th-order SA alone.

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INTRODUCTION

Standard intraocular lenses (IOLs) have positive spherical aberration (SA), which, when added to the positive SA in the normal cornea, increases ocular SA. Aspheric IOLs have been designed to compensate for the positive SA of the cornea.[1-4] Several aspheric IOLs with different amounts of asphericity are available. These include the Tecnis (SA = -0.27 µm for a 6-mm pupil; Advanced Medical Optics, Inc, Santa Ana, California), AcrySof IQ (SA = -0.20 µm; Alcon Laboratories, Inc, Fort Worth, Texas), and SofPort AO (SA = 0.00 µm; Bausch & Lomb Inc, Rochester, New York). Large ranges of corneal SA in the population have been reported.[5] Therefore, depending on an individual's corneal SA and the SA of the IOL selected, a wide range of residual ocular SA is possible for an eye undergoing IOL implantation.

It is well known that other higher-order aberrations (HOAs) exist in human cornea and that HOAs vary widely among subjects.[5] Applegate and colleagues[6] have reported that aberrations in different Zernike terms interact to increase or decrease optical performance. It is unclear what the optimal amount of SA would be in eyes with various HOAs. The purpose of this study was to investigate, based on anterior corneal HOAs, the optimal amount of ocular SA needed to maximize optical quality.

METHODS

PATIENTS

Institutional review board approval for retrospective chart review was obtained. A total of 154 eyes of 94 patients aged 40 to 80 years were included in this study. The cases were selected from our refractive surgery candidates and cataract patients; their HOAs have been reported previously.[7] Inclusion criteria were as follows:

- No previous ocular or corneal surgery
- No corneal pathology
- No contact lens wear *or* discontinuation of contact lens wear for 8 weeks for RGP lens, 4 weeks for toric soft lens, and 2 weeks for soft lens
- No missing data points within the central 7-mm zone on Humphrey Atlas corneal topographic maps (Carl Zeiss Meditec, Inc, Dublin, California)

SIMULATION OF ASPHERIC IOL IMPLANTATION

Corneal wavefront aberrations up to 6th order were computed from Humphrey Atlas corneal elevation data using the VOL-CT program (Sarver & Associates, Inc, Carbondale, Illinois), which uses the standards for calculating and reporting the optical aberrations

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of eyes as proposed by Thibos and colleagues.[8] The topographic maps were recentered around the entrance pupil, and wavefront aberrations from the cornea were calculated using corneal refractive index of 1.3771 for the wavelength of 555 nm.

In each eye, implantation of aspheric IOLs was simulated with different amounts of SA to produce residual ocular SA from -0.30 µm to +0.30 µm with intervals of 0.01 µm. The residual ocular wavefront aberrations were combined aberrations from the cornea and the aspheric IOLs. Thus, the residual ocular 4th-order SA ranged from -0.30 µm to +0.30 µm, and all other ocular HOAs equaled those in the anterior corneal surface.

SELECTION OF OPTIMAL SA

Using the ZernikeTool program (Advanced Medical Optics, Inc, Santa Ana, California),[9] the polychromatic point spread function (PSF) with Stiles-Crawford effect was calculated for the residual ocular HOAs (3rd to 6th order, 6-mm pupil), assuming full correction of 2nd-order aberrations. With this program, 7 wavelengths (400 nm, 450 nm, 500 nm, 550 nm, 600 nm, 650 nm, and 700 nm) were used to represent the visible spectrum, and the PSFs were weighted in the imaging plane based on the retinal spectral response function. The Stiles-Crawford effect was also incorporated in the calculation of polychromatic PSF. Five parameters were used to quantify the optical image quality:

1. Modulation transfer function (MTF) volume up to 30 cycles/degree. This is a 3-D volume under the MTF curve up to 30 cycles/degree, equivalent to visual acuity of 20/20.
2. MTF volume up to 15 cycles/degree: equivalent to visual acuity of 20/40.
3. Strehl ratio: ratio of peak focal intensities in aberrated PSF and ideal PSF. The Strehl ratio is 1 for a perfect optical system and less than 1 for an aberrated optical system.
4. Encircled energy (EE) at 2 arc minutes. The EE is a fractional energy within a given radius or field of view.
5. EE at 4 arc minutes.

We selected the residual ocular SA at which the maximal image quality was achieved as "optimal SA" for that eye. For example, if an eye had maximal MTF volume up to 30 cycles/degree at SA of -0.13 µm, this value would be the optimal SA for this eye for this parameter.

STATISTICAL ANALYSIS

For each eye and each parameter, the optimal residual ocular SA was determined in 0.01-µm intervals. These data were used in the Stepwise multiple regression analysis to assess the predictors for optimal SA of each eye (using SPSS 15.0 for Windows; SPSS Inc, Chicago, Illinois). However, for purposes of displaying data and discerning trends, eyes were grouped at 0.05-µm SA intervals. Thus, the optimal SA for each eye was rounded to the nearest SA in 0.05-µm intervals. For example, the reported optimal SA of 0 µm included values from -0.02 to +0.02 µm, and optimal SA of -0.05 µm included values from -0.07 to -0.03 µm.

RESULTS

The mean age of the 94 patients was 61 ± 12 years (range, 40-80 years). For a 6-mm pupil, the mean root-mean-square of the anterior corneal HOAs was 0.506 ± 0.130 µm (range, 0.234-0.857 µm), and 4th-order SA was +0.287 ± 0.090 µm (range, 0.076-0.544 µm).

DISTRIBUTION OF OPTIMAL SA

The optimal SA varied widely among eyes. The majority of eyes had best image quality with small amounts of negative SA.

For each parameter, optimal visual function was achieved for at least 25% of eyes at the following amounts of ocular SA: (1) MTF volume up to 30 cycles/degree: -0.05 µm and 0.00 µm (Figure 1); (2) MTF volume up to 15 cycles/degree: -0.05 µm (Figure 2); (3) Strehl ratio: -0.05 µm and 0.00 µm (Figure 3); (4) EE at 2 arc minutes: -0.05 µm and 0.00 µm (Figure 4); and (5) EE at 4 arc minutes: -0.10 µm and -0.05 µm (Figure 5).

PREDICTION OF OPTIMAL SA

For MTF volume up to 30 cycles/degree, 8 higher-order Zernike terms predicted the optimal SA with a multiple correlation coefficient R of 0.794. The order of importance of the 8 predictors to optimal SA from most to least was as follows: Z_6^0, Z_6^2, Z_3^3, Z_5^3, Z_6^4, Z_3^{-1}, Z_4^2, and Z_3^1. The multiple regression equation for optimal SA was:

$$C_4^0 = 1.75C_6^0+0.51C_6^2-0.07C_3^3 -0.26C_5^3+0.31C_6^4 +0.05C_3^{-1}-0.1C_4^2-0.04C_3^1-0.05$$

For MTF volume up to 15 cycles/degree, 8 Zernike terms predicted the optimal SA with a multiple correlation coefficient R of 0.889. The 8 predictors were the same 8 Zernike terms as in the model for MTF volume up to 30 cycles/degree, but with a slightly different order of importance (from most to least): Z_6^0, Z_6^2, Z_4^2, Z_5^3, Z_6^4, Z_3^{-1}, Z_3^3, and Z_3^1. The multiple regression equation for optimal SA was:

$$C_4^0 = 1.48C_6^0+0.29C_6^2-0.11C_4^2-0.21C_5^3+0.22C_6^4 +0.03C_3^{-1} -0.04C_3^3 -0.02C_3^1-0.06$$

For Strehl ratio, 4 Zernike terms predicted the optimal SA with a lower multiple correlation coefficient (R = 0.611) compared with those for MTF volume. The order of importance of the 4 predictors to optimal SA from most to least was as follows: Z_4^2, Z_6^0, Z_5^1, and Z_3^1. For EE at 2 arc minutes, 6 predictors significantly contributed to the model with R value of 0.563 (Z_6^0, Z_4^2, Z_3^{-1}, Z_3^3, Z_6^{-4}, and Z_5^5). For EE at 4 arc minutes, 3 predictors significantly contributed to the model with R value of 0.608 (Z_6^0, Z_6^6, and Z_6^{-2}).

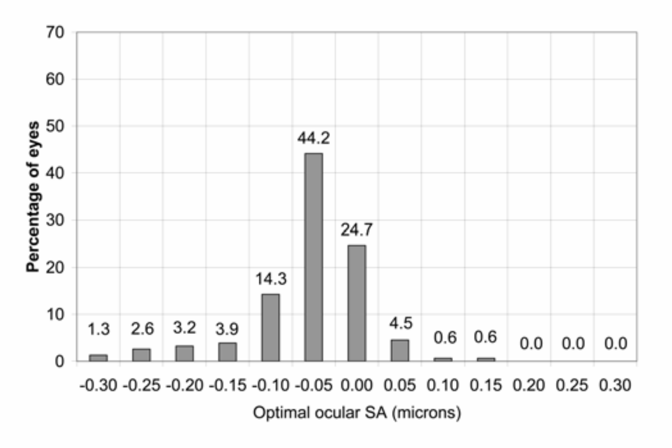

FIGURE 1

Distribution of optimal ocular spherical aberration (SA, C_4^0) to produce best image quality as evaluated by modulation transfer function volume up to 30 cycles/degree. The optimal SA was rounded to the nearest SA in 0.05-µm intervals. For example, the reported optimal SA of 0 µm included values from -0.02 to +0.02 µm, and optimal SA of -0.05 µm included values from -0.07 to -0.03 µm.

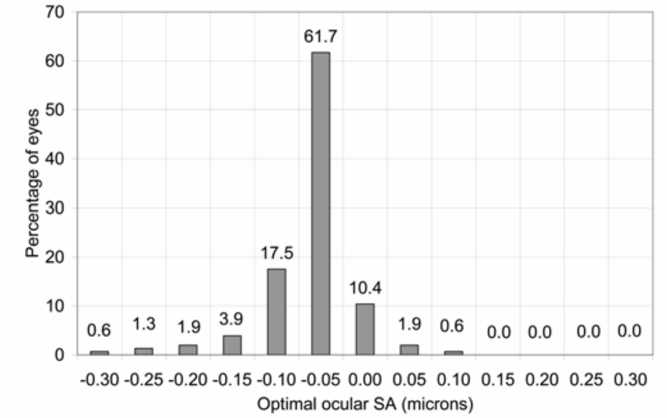

FIGURE 2

Distribution of optimal ocular spherical aberration (SA, C_4^0) to produce best image quality as evaluated by modulation transfer function volume up to 15 cycles/degree. The optimal SA was rounded to the nearest SA in 0.05-µm intervals. For example, the reported optimal SA of 0 µm included values from -0.02 to +0.02 µm, and optimal SA of -0.05 µm included values from -0.07 to -0.03 µm.

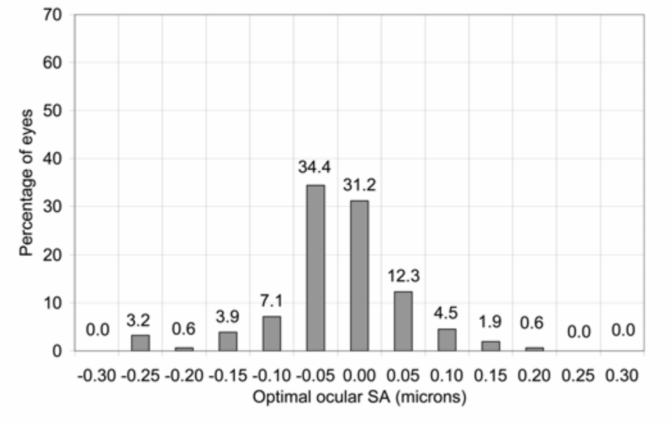

FIGURE 3

Distribution of optimal ocular spherical aberration (SA, C_4^0) to produce best image quality as evaluated by Strehl ratio. The optimal SA was rounded to the nearest SA in 0.05-µm intervals. For example, the reported optimal SA of 0 µm included values from -0.02 to +0.02 µm, and optimal SA of -0.05 µm included values from -0.07 to -0.03 µm.

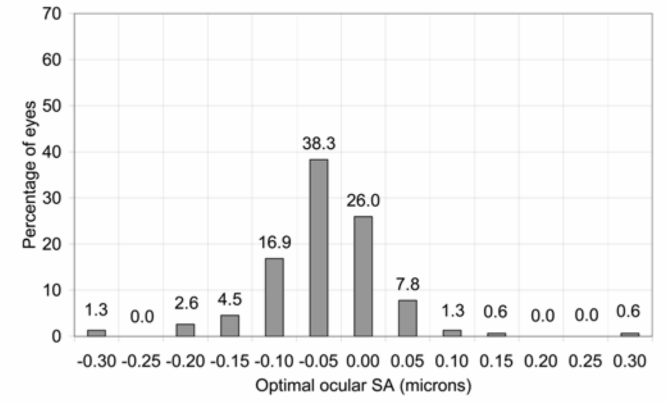

FIGURE 4

Distribution of optimal ocular spherical aberration (SA, C_4^0) to produce best image quality as evaluated by encircled energy at 2 arc minutes. The optimal SA was rounded to the nearest SA in 0.05-µm intervals. For example, the reported optimal SA of 0 µm included values from -0.02 to +0.02 µm, and optimal SA of -0.05 µm included values from -0.07 to -0.03 µm.

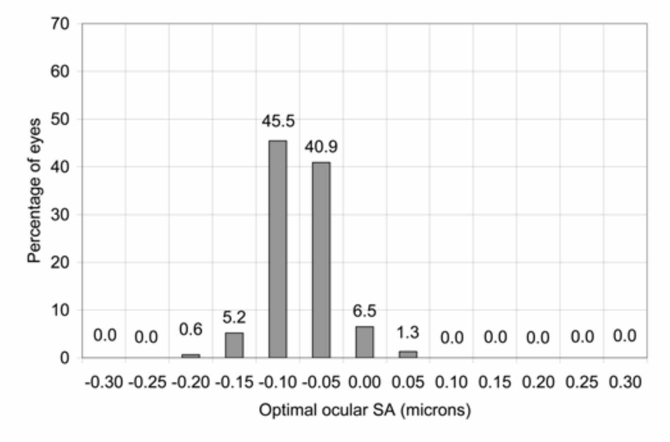

FIGURE 5

Distribution of optimal ocular spherical aberration (SA, C_4^0) to produce best image quality as evaluated by encircled energy at 4 arc minutes. The optimal SA was rounded to the nearest SA in 0.05-µm intervals. For example, the reported optimal SA of 0 µm included values from -0.02 to +0.02 µm, and optimal SA of -0.05 µm included values from -0.07 to -0.03 µm.

DISCUSSION

There are two primary reasons to customize the asphericity of the IOL for each eye: (1) There is a wide range of corneal SA in the population. (2) As shown in this study, other higher-order corneal aberrations interact variably with SA to increase or decrease optical performance. Applegate and colleagues[6] investigated how pairs of Zernike modes interact to increase or decrease visual acuity. They found that acuity varied significantly, depending on the modes that were selected and the relative contribution of each mode. Two modes 2 radial orders apart and having the same sign and angular frequency combined to increase visual acuity, whereas 2 modes within the same radial order combined to decrease acuity. We are unaware of any studies investigating what the optimal amount of SA would be in eyes with various corneal HOAs.

In this study, we evaluated the optimal amount of ocular SA needed to maximize optical quality in patients in the cataract age range (40-80 years). To account for chromatic aberrations and the Stiles-Crawford effect in the human eye, the polychromatic PSF was calculated with Stiles-Crawford effect incorporated; the goal was to simulate the image quality a subject might experience in the white-light environment. Five parameters were used to quantify the optical image quality of the eye. Various metrics evaluating optical quality have been studied,[10-12] and controversy exists regarding which metric or combination of metrics best predicts quality of vision.

We found that most eyes did not have best image quality at SA of 0 µm and that the optimal SA varied widely among eyes. For 4 of the 5 parameters that were used to predict optical image quality of the eye (MTF volume up to 30 cycles/degree, MTF volume up to 15 cycles/degree, Strehl ratio, and EE at 2 arc minutes), the highest percentage of eyes had best image quality at residual ocular SA of -0.05 µm (34.4%-61.7%). With the EE at 4 arc minutes, the highest percentage of eyes had best image quality at residual ocular SA of -0.10 µm (45.5%).

Using the stepwise multiple regression analysis, we found that the amount of optimal SA could be predicted based on other HOAs of the cornea with a coefficient of multiple determination (R^2) up to 79% for MTF volume up to 15 cycles/degree, indicating that 79% of the variation in the optimal SA is accounted for by the 8 Zernike terms included in the model. The R^2 values were 63% for MTF volume up to 30 cycles/degree, and 32% to 37% for Strehl ratio and EE at 2 and 4 arc minutes, respectively. Among the Zernike terms that significantly contributed to the optimal SA, 6th-order SA (Z_6^0) made the greatest contribution for 4 of the 5 parameters evaluated in this study. This demonstrates aberration interactions among Zernike terms as reported by Applegate and colleagues.[6]

Both in the laboratory by using adaptive optics[3] and in clinical studies, aspheric IOLs have been shown to reduce ocular SAs, improve contrast sensitivity, and improve night driving performance.[2,4] However, 2 recent studies[13,14] reported no differences between aspheric and spherical IOLs in low-contrast visual acuity, high-contrast visual acuity, and contrast sensitivity. Although multiple factors may contribute to these conflicting findings, lack of optimization of residual ocular SA might play a role. In the subjects included in this study, the corneal 4th-order SA ranged from 0.076 µm to 0.544 µm. Assuming implantation of Tecnis lens, AcrySof IQ lens, SofPort AO lens, and standard IOL with positive SA (SA = +0.18 µm) in these eyes, the residual ocular SA would range from

-0.194 to 0.274 µm, -0.124 to 0.344 µm, 0.076 to 0.544 µm, and 0.256 to 0.724 µm, respectively. This spectrum of SA data may explain, at least in part, variations in studies' results.

Limitations of the study included the following:

1. This was a theoretical study, not a clinical study.
2. We assumed that the 2nd-order aberrations (defocus and astigmatism) were fully corrected by some means, such as spectacles, following cataract surgery; the optimal SA would differ as a function of residual defocus or/and astigmatism.
3. Calculations were made for a 6-mm pupil; the impact of residual SA will be less with a smaller pupil, and the optimal value for each eye might change as pupil size changes.
4. This study assumed that the aspheric IOLs were well centered and not tilted; decentration of aspheric IOLs induces coma,[7,15] which may affect the amount of optimal SA for that eye.
5. This study did not evaluate the effect of optimization of SA on depth of focus.
6. This study ignored the neuroadaptive response. Using an adaptive optics system, Artal and colleagues[16] found that the stimulus seen with the subject's own aberrations was always sharper than when seen through the rotated version, but that subjects were capable of readapting to new HOAs; the magnitude and timing of this response is under study. Webster and associates[17] reported that neural adaptation could also profoundly affect the actual perception of image focus.

In summary, the results of this study demonstrated that the optimal SA producing best image quality varied widely among subjects and could be predicted based on other HOAs. Customization of IOL selection should be based on the full spectrum of preexisting corneal HOAs and not on 4th-order SA alone. Further theoretical and clinical studies are desirable to address issues such as decentration, tilt, depth of focus, and, of course, clinical assessment of quality of vision.

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Author Contributions: *Design and conduct of the study* (D.D.K., L.W.); *Collection, management, analysis, and interpretation of the data* (D.D.K., L.W.); *Preparation, review, and approval of the manuscript* (D.D.K., L.W.).

REFERENCES

1. Holladay JT, Piers PA, Koranyi G, van der Mooren M, Norrby NE. A new intraocular lens design to reduce spherical aberration of pseudophakic eyes. *J Refract Surg* 2002;18:683-691.
2. Packer M, Fine IH, Hoffman RS, Piers PA. Prospective randomized trial of an anterior surface modified prolate intraocular lens. *J Refract Surg* 2002;18:692-696.
3. Piers PA, Fernandez EJ, Manzanera S, Norrby S, Artal P. Adaptive optics simulation of intraocular lenses with modified spherical aberration. *Invest Ophthalmol Vis Sci* 2004;45:4601-4610.
4. Bellucci R, Scialdone A, Buratto L, et al. Visual acuity and contrast sensitivity comparison between Tecnis and AcrySof SA60AT intraocular lenses: a multicenter randomized study. *J Cataract Refract Surg* 2005;31:712-717.
5. Wang L, Dai E, Koch DD, Nathoo A. Optical aberrations of the human anterior cornea. *J Cataract Refract Surg* 2003;29:1514-1521.
6. Applegate RA, Marsack JD, Ramos R, Sarver EJ. Interaction between aberrations to improve or reduce visual performance. *J Cataract Refract Surg* 2003;29:1487-1495.
7. Wang L, Koch DD. Effect of decentration of wavefront-corrected intraocular lenses on the higher-order aberrations of the eye. *Arch Ophthalmol* 2005;123:1226-1230.
8. Thibos LN, Applegate RA, Schwiegerling JT, et al. Standards for reporting the optical aberrations of eyes. In: MacRae SM, Krueger RR, Applegate RA, eds. *Customized Corneal Ablation: The Quest for SuperVision*. Thorofare, NJ: Slack, Inc; 2001:348-361.
9. Dai GM. Optical surface optimization for the correction of presbyopia. *Appl Opt* 2006;45:4184-4195.
10. Chen L, Singer B, Guirao A, Porter J, Williams DR. Image metrics for predicting subjective image quality. *Optom Vis Sci* 2005;82:358-369.
11. Marsack JD, Thibos LN, Applegate RA. Metrics of optical quality derived from wave aberrations predict visual performance. *J Vis* 2004;4:322-328.
12. Applegate RA, Marsack JD, Thibos LN. Metrics of retinal image quality predict visual performance in eyes with 20/17 or better visual acuity. *Optom Vis Sci* 2006;83:635-640.
13. Kurz S, Krummenauer F, Thieme H, Dick HB. Contrast sensitivity after implantation of a spherical versus an aspherical intraocular lens in biaxial microincision cataract surgery. *J Cataract Refract Surg* 2007;33:393-400.
14. Kasper T, Buhren J, Kohnen T. Visual performance of aspherical and spherical intraocular lenses: intraindividual comparison of visual acuity, contrast sensitivity, and higher-order aberrations. *J Cataract Refract Surg* 2006;32:2022-2029.

15. Altmann GE, Nichamin LD, Lane SS, Pepose JS. Optical performance of 3 intraocular lens designs in the presence of decentration. *J Cataract Refract Surg* 2005;31:574-585.
16. Artal P, Chen L, Fernandez EJ, Singer B, Manzanera S, Williams DR. Neural compensation for the eye's optical aberrations. *J Vis* 2004;4:281-287.
17. Webster MA, Georgeson MA, Webster SM. Neural adjustments to image blur. *Nat Neurosci* 2002;5:839-840.

PEER DISCUSSION

DR HENRY GELENDER: The investigation and understanding of the wavefront aberrations of the eye has been applied to refractive corneal surgery, such as LASIK and PRK. As a result, customized refractive surgery now affords improved visual outcomes for these refractive procedures. Now these same principles are being applied to implant technology and cataract surgery. The authors, in a previously published article titled "Optical Aberrations of the Human Anterior Cornea," have shown that anterior corneal wavefront aberrations vary among subjects and increase with age.[1] Moreover, they have shown that all corneas studied had positive Zernike 4th-order spherical aberrations (SAs). In this study, the authors continue their investigations using a theoretical model for studying the optimal amount of SA, which when applied to an intraocular lens would maximize the optical quality following cataract surgery. They found that the optimal SA producing best image quality varied widely among subjects. Additionally, they found that multiple Zernike terms contributed to the optimal SA. From their studies they conclude that the full spectrum of corneal higher-order aberrations (HOAs) should be considered and not just the 4th-order SA.

Aspheric intraocular lenses have been developed, whereby the aspheric design of the implant can offset the SA of the cornea, attempting to mimic the crystalline lens of youth for improved image quality. However, current aspheric implants are available in a standard "one size fits all" approach. As the authors imply from their study, customized implants would need to be produced to compensate a variety of corneal HOAs. This begs the question, Is this practical for implant manufacturers? It has also been shown that the resultant wavefront aberrations after cataract surgery are affected by implant decentration, tilt, and rotation as well as the effect of corneal incision size, location, and wound healing.[2] These factors, which may only be assessed postoperatively, may offset the benefit of wavefront modified implants, which have been selected on the basis of preoperative corneal HOA. Ultimately, customized corneal refractive surgery may be used following the cataract surgery to correct the induced or residual optical aberrations of the eye. This could be additive to the benefits of customized, HOA-correcting implants. Also intriguing is the possibility of using light-adjustable lenses, which can be treated postoperatively to correct the residual HOAs. This technique was reported at last year's AOS meeting.[3]

The authors rightfully point out that their study is limited as a theoretical study. Clinical studies are necessary to assess the effect of optical aberrations on image quality after cataract surgery. The authors are to be congratulated for the design and execution of their study. The information reported is incremental to our understanding of the complex nature of how aberrations of the eye affect visual outcomes from cataract surgery.

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REFERENCES

1. Wang L, Dai E, Koch DD, Nathoo A. Optical aberration of the human anterior cornea. *J Cataract Refract Surg* 2003;29:1514-1521.
2. Wang L, Koch DD. Effect of decentration of wavefront-corrected intraocular lenses on the higher-order aberrations of the eye. *Arch Ophthalmol* 2005;123:1226-1230.
3. Sandstedt CA, Chang SH, Grubbs RH, Schwartz DM. Light-adjustable lens: customizing correction for multifocality and higher-order aberrations. *Trans Am Ophthalmol Soc* 2006;104:29-39.

DR. ROBERT C. DREWS: No commercial interest. With sincere respect, and I mean that Doug, how many of your postoperative cataracts patients had 6 mm pupils, and what happens to the importance of the spherical aberrations with a 2.5 mm pupil?

DR. DOUGLAS R. ANDERSON: No conflicts that pertain to this presentation. My question is very similar, but it has another twist to it. That is, the size of the pupil does matter, and it determines how much of the cornea is being used. We are talking about the spherical aberration of the entire cornea including the periphery in studying the higher-order aberrations particularly. In addition to that, the fovea is the only place or the main place where a crisp image makes a difference for the ability to see and, in particular, the fovea uses only a central circle of the cornea. I wonder whether it makes any sense to measure these higher-order aberrations over the entire cornea, but perhaps over just the central 4 or 5 mm of the cornea, which is the area contributing light toward fovea.

DR. GEORGE O. WARING, III: Consultant for American Medical Optics and Calhoun Vision. We are hearing a lot about accommodative intraocular lenses. Could you comment on that since yours is a theoretical study on the possible impact of accommodative IOLs with the higher-order aberrations?

DR. GEORGE L. SPAETH: Doug that is fascinating. It is a fact that people who are missing parts of their visual field fill those in so that they function very well. There is little correlation between the amount of visual field loss and the actual disability because of cortical plasticity. Some people seem to be able to do that much better than others. Some people tolerate the accommodative lenses better than others. Are you or others working on trying to figure out why it is that some people can handle that sort of visual problem more successfully than others?

DR. DOUGLAS D. KOCH: I would like to thank everyone for their very interesting and relevant comments. Dr. Gelender's point about postoperative modification is intriguing and is an area of intense investigation. We heard last year about the Calhoun lens, which offers the possibility of modifying the power and aberrations of an intraocular lens postoperatively. In the Calhoun clinical trial, spherical aberration was corrected in a patient after cataract surgery by irradiating the lens. The comments of Drs. Drews and Anderson on pupil size are important. Clearly, the data I have presented represent the worse case scenario of a 6 mm pupil. The impact of the aberrations diminishes as pupil size diminishes. On the other hand, we are doing more and more lens surgery on young people in their forties and fifties who have large pupils. They easily dilate to 6 mm and larger at night, so it is highly relevant for them. Dr. Waring inquires about quality of vision with accommodating IOLs. I presented a paper on this subject at the recent ASCRS meeting. There are data to suggest that decentration and tilt are not a major problem, but there is a more work to be done on this issue. Dr. Spaeth asked if we can predict which patients can adapt to which IOLs. There are two relevant categories to consider, the first of which is multifocal IOLs. I think most clinicians today who are using these IOLs still find it to be a conundrum to select patients who uniformly either will or will not like these lenses. I find it a matter of great frustration in my practice. This suggests that patient histories and patient personality profiles are not the whole picture. I believe that unknown factors at the level of retinal or CNS neural processing are involved. The second area is monovision, which is more predictable but again is subject to some variability in patients' ability to adapt to and accept it. One of our new inductees, Dan Durrie, did a very nice thesis on the issue of adaptation to monovision, and we are learning more about that as well.