

Aspheric Intraocular Lenses

Y. Ralph Chu, MD

With continued improvements in surgical techniques, biometry, and intraocular lens (IOL) technology, cataract surgeons have for some time been capable of consistently achieving highly accurate quantitative refractive results following cataract/lens replacement surgery. We know we can improve an individual's vision from 20/400 to 20/20, for example.

The modern cataract surgeon, however, is now embarking on the quest for "perfect vision" beyond a simple 20/20 standard. This does not necessarily mean getting the patient to 20/10. Rather, it means that we have started paying attention to other aspects of vision beyond Snellen acuity, such as contrast sensitivity and wavefront error, in order to achieve the highest possible quality of vision. Cataract surgeons are becoming refractive surgeons, and IOL manufacturers are beginning to incorporate advanced refractive technology toward the same objective.

Aspheric IOLs are the first new technology IOLs to reflect the refractive shift in cataract surgery.

THE IMPORTANCE OF ASPHERICITY

A decade ago, Jack Holladay introduced us to the importance of asphericity in his famous discus-

sion of the vision of frogs and eagles. Glasser and Campbell had shown that spherical aberration (SA) of the crystalline lens changes considerably with age, moving from a negative SA value to a positive one.¹ Jack Holladay further demonstrated that side effects of myopic LASIK were likely due to the fact that the procedure turned a prolate human eye into an oblate one, with a sphericity or Q-value more akin to that of a frog than of a predator eagle.² The role of SA in the aging eye suddenly became much more interesting.

The average sphericity of the normal human cornea is positive and remains stable throughout life, but the lens SA changes with age. In the young eye, the negative SA of the crystalline lens balances the positive SA of the cornea, resulting in zero or very low total ocular SA.³ Light is sharply focused on the retina, producing a quality image and good functional vision (Figure 13-1). But in older eyes, the crystalline lens loses the ability to compensate for corneal SA, total ocular SA becomes increasingly positive, and the resulting aberrations cause blurred vision and reduced contrast sensitivity, affecting functional vision (Figure 13-2).

We also know that with age, contrast sensitivity decreases, first at the higher spatial frequencies, then at all the spatial frequencies⁴ (Figure 13-3).

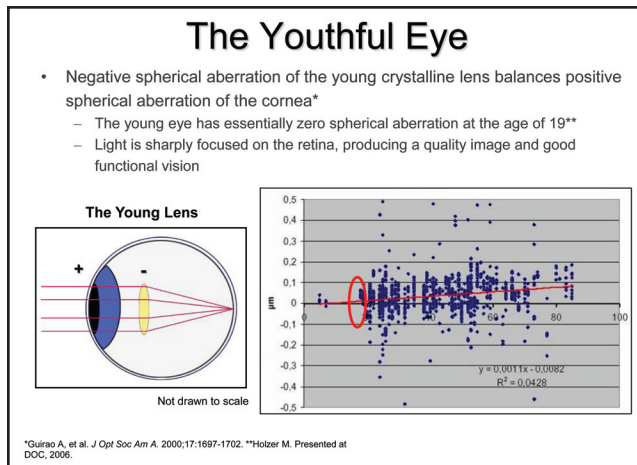


Figure 13-1. The young eye has essentially zero spherical aberration at age 19.

The loss of functional vision can decrease quality of life and compromise driving safety even with continued good Snellen acuity. And of course, the onset of cataract exacerbates any pre-existing functional vision problems. Traditional spherical IOLs typically add positive SA, keeping total SA similar to that found in the aging natural lens.

Some people have argued that an advantage of positive SA in the aging eye is an increased depth of focus. The corollary to that, of course, would be that sharpening distance vision by correcting SA with an aspheric IOL might worsen near and intermediate vision. Certainly, this is a concern for anyone who wants his or her patients to be satisfied with their entire visual experience after IOL surgery.

However, several recent publications refute this argument. Jack Holladay points out that spherical and aspheric lenses do not differ at all in the depth of focus, but only in the clarity of best focus.⁵ Additionally, he says that slightly negative SA may actually have an accommodative effect when the pupil constricts for near tasks, depending on the lens that is used. Nishi also shows a significant negative correlation between range of accommodation and SA.⁶ In other words, lower SA is correlated with better accommodation. Finally, Wang and Koch recently demonstrated that when all aberrations are corrected, eyes with zero SA have the best depth of focus.⁷ If SA was not zero, they also found that slightly negative SA, rather than slightly positive SA, provided better depth of focus.

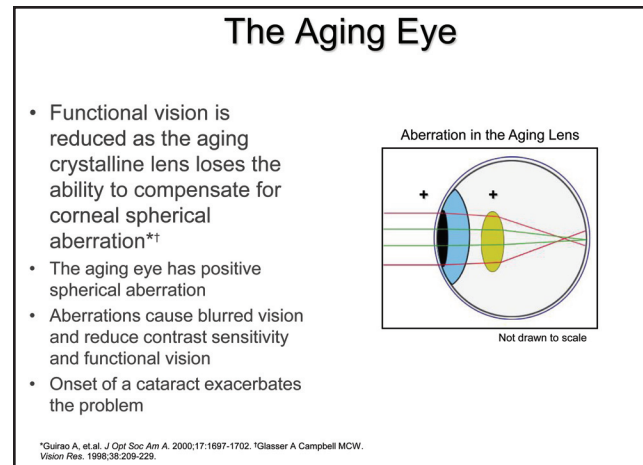


Figure 13-2. The aging eye has positive spherical aberration reducing functional visual acuity.

Why Target Zero Spherical Aberration?

- Multiple studies show peak visual performance occurs at age 19, when the average spherical aberration is 0.0 microns*
- As spherical aberration increases with age, contrast sensitivity decreases†

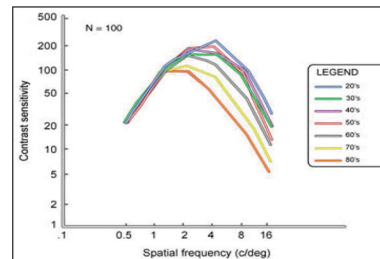


Figure 13-3. Contrast sensitivity decreases with age.

INTRODUCTION OF THE FIRST ASPHERIC INTRAOCULAR LENS

Recognizing that a reduction in total ocular SA could potentially improve contrast sensitivity in the aging eye, optical scientists set out to create an IOL that could rebalance total ocular SA.

Corneal topography measurements on 71 cataract patients showed that the average SA of the human cornea was +0.27 microns.⁸ This was subsequently confirmed in several other studies.^{9,10} A model cornea based on these measurements was used to design IOLs having a fixed amount of negative SA to compensate for the positive SA of the average human cornea.

From these modeling experiments, the Tecnis Z9000 wavefront-designed IOL (AMO, Santa Ana, CA) was born. In testing of 25 patients aged 60 and

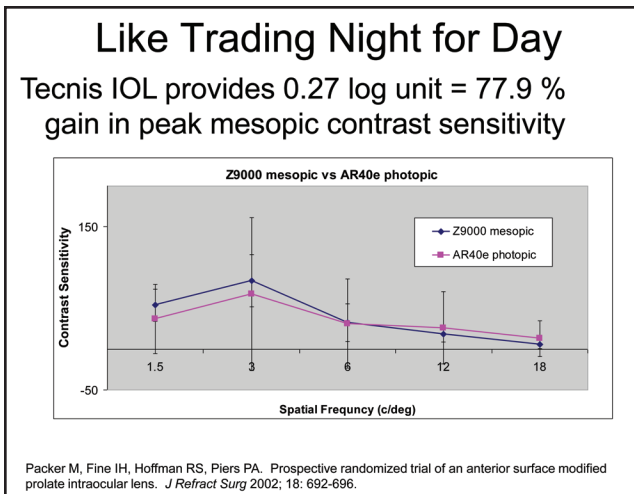


Figure 13-4. In this study, the contrast sensitivity of the Tecnis aspheric IOL was as good as a spherical IOL under photopic conditions.

older implanted with the Tecnis aspheric IOL, total ocular SA was not significantly different from zero, so the lens is effective in reaching the intended target.

A prospective randomized study showed a nearly 78% gain in peak contrast sensitivity with the new lens, with mesopic contrast sensitivity approximately equivalent to photopic contrast sensitivity with a spherical lens¹¹ (Figure 13-4). Early European studies also showed that it could improve visual quality.^{12,13}

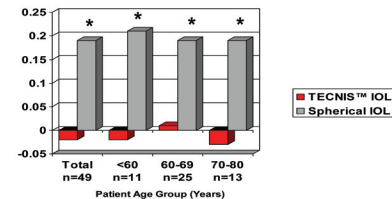
In controlled, multicenter, US clinical trials (n=78), SA was significantly less 3 months post-implantation of the Tecnis lens than after implantation of a spherical acrylic IOL. The benefit was independent of age¹⁴ (Figure 13-5).

Driving simulations were also conducted as part of the US Food and Drug Administration (FDA) clinical trials to determine the impact of the lens on functional vision. Patients viewing a simulated nighttime rural road through a Tecnis aspheric lens identified a pedestrian in the road significantly faster than patients viewing through a spherical lens.¹⁴ On average, patients with Tecnis lenses saw the pedestrian 0.50 seconds sooner than the spherical IOL patients, which gave them a 45-foot advantage to react to the hazard in the road. Many recent vehicular safety improvements that are now standard on automobiles improve braking time by just 0.11 to 0.35 seconds.

The FDA approved the Tecnis lens in 2004, with the unprecedented claim that it was likely to offer a meaningful safety benefit for elderly drivers and others with whom they share the road. Moreover, the

Spherical Aberration Reduced to Essentially Zero*

Total ocular spherical aberration of TECNIS™ eyes is not significantly different from zero†



Mean Spherical Aberration Measurements, 90 15 Days Postoperatively, Study 001: Z9000: N=25; Lens with Spherical Optic: N=24 †

*Package insert, TECNIS™ Foldable Posterior Chamber Intraocular Lens, Advanced Medical Optics, Inc.
†The data as it appears here follows the OSA standard and has been changed from the original data to reflect a difference in sign (+ or -) that exists between the WASCAs measurement and the OSA standard.

Figure 13-5. FDA clinical trial data showing essentially zero spherical aberration.

improvement in functional vision may improve patient safety for other situations in which visibility is low.

Since then, it has been shown that this lens provides uncorrected and distance-corrected near visual acuity similar to that obtained with standard spherical monofocal lenses, so there does not appear to be any loss of depth of focus from correction of the positive SA.¹⁵

AN EVOLVING MARKET

Since 2004, other lens manufacturers have introduced other concepts of asphericity, with new aspheric lenses of their own.

The Acrysof IQ IOL (SN60WF, Alcon, Fort Worth, TX) was designed to partially compensate for the SA of a model eye. The lens has an aspheric posterior optic design with a thinner center. It induces -0.15 microns of SA, compared to the -0.27 microns induced by the Tecnis lens, leaving approximately 0.1 microns of positive SA in the average cornea.

Some studies have shown that Navy aviators with excellent visual abilities have small amounts of SA, so in theory, leaving a small amount of residual SA might be a good thing. However, Steve Schallhorn, who conducted the pilot studies, continues to believe that striving for zero SA remains the most effective target. In his aviator studies, those subjects with SA closer to zero had better mesopic contrast acuity than their fellow pilots with higher SA.¹⁶

Other human studies have also shown that superior youthful vision is associated with zero SA. Pablo Artal

presented a study at the 2006 European Society of Cataract and Refractive Surgeons showing that young subjects with naturally occurring supernormal vision of 20/15 or better have zero SA (average 0.02 microns). Doug Koch recently reported that even though optimal ocular and IOL SA varies widely among eyes, most emmetropic eyes achieved the best image quality with a 6.0-mm pupil when total ocular SA is between -0.10 to 0.00 microns.⁷

McCulley and colleagues showed that the Acrysof IQ aspheric lens reduces the positive ocular spherical aberration observed in pseudophakic and elderly eyes, especially at larger pupillary diameters (6 mm), with no notable increase in coma.¹⁷ With a 6.0-mm pupil, total SA post-implantation was very close to predicted levels, at 0.09 ± 0.04 microns, compared to 0.43 ± 0.12 microns for patients implanted with Acrysof spherical IOLs ($p < 0.0001$).

In a recent prospective study, the aspheric IQ lens provided significantly better contrast sensitivity at all spatial frequencies during mesopic testing, with and without glare, than two other spherical Acrysof lenses.¹⁸

A third aspheric IOL, the Sofport AO (LI61AO, Bausch & Lomb, Rochester, NY) was designed to be SA neutral, not adding to or subtracting from the corneal SA.

Because the AO lens has no relationship to the average or actual SA in the eye, it may be less dependent on centration. Nichamin and colleagues found that the optical performance of a model eye was not affected by decentration of the AO, even when the lens was decentered by as much as 1.00 mm.¹⁹ In this decentration model, the lens performed better than both a spherical IOL and an aspheric IOL designed to offset SA (Tecnis).

Tolerance levels for the Tecnis aspheric lens require that it be decentered less than 0.4 mm and tilted less than 7 degrees in order to provide optical performance superior to that of a spherical lens. Newer studies have shown that the above values applied to monochromatic light only. In a more real-world situation where polychromatic light is present, the above values nearly double, with about 0.8 mm of decentration and more than 10 degrees of tilt being tolerated.²⁰ A number of published studies over the past decade or more have shown that with a continuous curvilinear capsulorrhexis and in-the-bag IOL placement, modern cataract surgery is typically well within such tolerance limits.²¹⁻²³

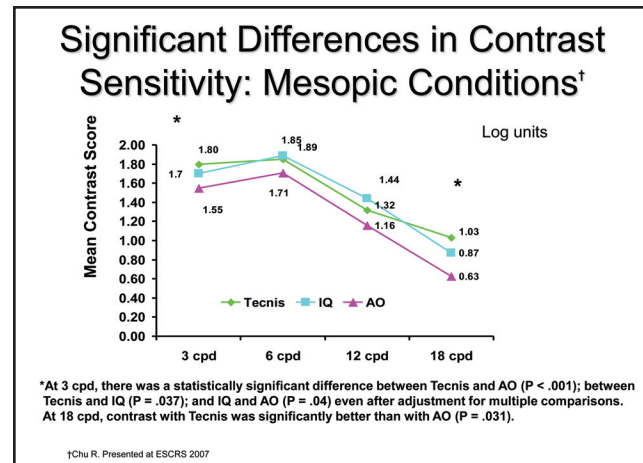


Figure 13-6. Mesopic contrast sensitivity results from our clinical comparison of three different aspheric lenses.

COMPARISON STUDY

I am conducting a monocular, randomized, double-masked, parallel group study comparing the three aspheric IOLs in our practice. To date, 79 subjects have been enrolled and randomized to the SofPort AO, the Acrysof IQ, or the Tecnis IOL, without regard to preoperative corneal SA. Enrollment and follow-up are ongoing.

Thus far, Snellen visual acuity outcomes have been uniformly excellent, with an average postoperative best corrected visual acuity better than 20/20 in all three lens groups.

Of course, we are very interested in what happens to SA in these eyes. At 3 months postoperative, with a 5.0-mm pupil, patients with the Tecnis (0.01) and Acrysof IQ (0.04) lenses had statistically significantly less SA than patients with the SofPort AO (0.11). The Tecnis aspheric—and, to a lesser degree, the IQ lens—effectively compensates for the SA in the average eye.

We are also interested in measures of the quality of vision under low contrast or low light conditions where we would expect SA to be problematic. There are significant differences in contrast sensitivity at 3 and 18 cycles per degree favoring the Tecnis lens, under both mesopic (Figure 13-6) and photopic (Figure 13-7) conditions.

SURGICAL PEARLS

In almost all situations in which a monofocal lens is to be implanted, an aspheric lens will provide the

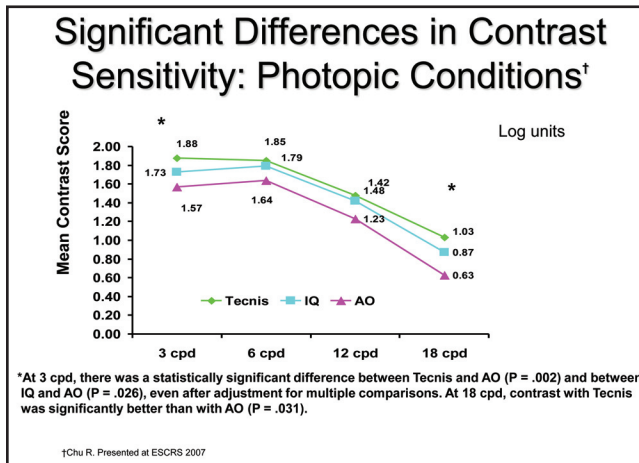


Figure 13-7. Photopic contrast sensitivity results from our clinical comparison of three different aspheric lenses.

highest quality vision—and may even improve Snellen visual acuity, as our anecdotal experience seems to suggest. The one exception to this rule is the patient who has had previous hyperopic laser refractive surgery. If the correction was for significant hyperopia (+2.0 diopters or greater), the cornea will already have low or negative SA, and an aspheric lens implant can actually increase the total negative SA of the ocular system.

Some surgeons may prefer to measure corneal SA preoperatively and base their lens decision on which of the three aspheric lenses is the most likely to bring the patient's total SA back into balance at zero. For the majority of patients, the Tecnis IOL is the most likely to achieve the zero SA target.

Of course, in addition to choosing an appropriate aspheric IOL, surgeons should also take care to maximize visual function with these lenses by fully correcting lower order aberrations. This requires the use of optimized IOL constants for biometry and correction of astigmatism with limbal relaxing incisions or by other means.

A good surgical technique with appropriate capsulorrhexis and in-the-bag positioning is important. One-piece and three-piece aspheric lenses are available. To maintain adequate centration during a complicated case, such as one in which there is a break in the capsular bag that requires sulcus placement, a three-piece lens is necessary.

Because these lenses have aspheric surfaces on only one side, I have often been asked what would happen if the lens is implanted upside down. The answer is that the patient will still benefit from the asphericity of the lens, although the refraction may be off.

CONCLUSION

Aspheric IOLs are here to stay and are rapidly becoming the standard of care because they can potentially provide superior optical quality, especially in low light and low contrast situations.

I believe that aspheric IOLs represent the first truly refractive IOLs. They offer an easy way for the general cataract surgeon to begin making the transition to refractive cataract surgeon. Once one has implemented the steps necessary for implanting aspheric lenses (eg, precision biometry, correction of preoperative astigmatism at the time of surgery), one can more easily consider other premium IOLs, including those with multifocal or accommodating surfaces.

As we develop better ways of measuring preoperative corneal SA, we may find ourselves customizing the IOL to not only the axial length, but also to the patient's individual corneal SA, in an attempt to optimize vision. And, farther in the future, we may be customizing IOLs to a whole range of quality of vision factors as the quest for "perfect vision" evolves.

REFERENCES

1. Glasser A, Campbell MC. Presbyopia and the optical changes in the human crystalline lens with age. *Vision Res.* 1998;38(2):209-229.
2. Holladay JT, Dudeja DR, Chang J. Functional vision and corneal changes after laser in situ keratomileusis determined by contrast sensitivity, glare testing, and corneal topography. *J Cataract Refract Surg.* 1999;25(5):663-669.
3. Guirao A, Redondo M, Artal P. Optical aberrations of the human cornea as a function of age. *J Opt Soc Am A Opt Image Sci Vis.* 2000;17(10):1697-1702.
4. Owsley C, Sekuler R, Siemsen D. Contrast sensitivity throughout adulthood. *Vision Res.* 1983;23:689-699.
5. Holladay JT. Spherical aberration: the next frontier. *Cataract Refract Surg Today.* 2006;Nov-Dec:95-106.
6. Nishi T, Nawa Y, Ueda T, et al. Effect of total higher-order aberrations on accommodation in pseudophakic eyes. *J Cataract Refract Surg.* 2006;32:1643-1649.
7. Wang L, Koch DD. Custom optimization of intraocular lens asphericity. *J Cataract Refract Surg.* 2007;33:1713-1720.
8. Holladay JT, Piers PA, Koranyi G, et al. A new intraocular lens design to reduce spherical aberration of pseudophakic eyes. *J Refract Surg.* 2002;18(6):683-691.
9. Wang L, Dai E, Koch DD, Nathoo A. Optical aberrations of the human anterior cornea. *J Cataract Refract Surg.* 2003;29(8):1514-1521.
10. Guirao A, Tejedro J, Artal P. Corneal aberrations before and after small-incision cataract surgery. *Invest Ophthalmol Vis Sci.* 2004;45(12):4312-4319.
11. 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.
12. Mester U, Dillinger P, Anterist N. Impact of a modified optic design on visual function: clinical comparative study. *J Cata-*

- ract Refract Surg.* 2003;29(4):652-660.
13. Bellucci R, Morselli S, Piers P. Comparison of wavefront aberrations and optical quality of eyes implanted with five different intraocular lenses. *J Refract Surg.* 2004;20(4):297-306.
 14. Package insert. TECNIS™ foldable posterior chamber intraocular lens. Advanced Medical Optics, Inc.
 15. Packer M, Fine IH, Hoffman RS. Visual acuity at distance and near with monocular and binocular monofocal aspheric Tecnis IOL. Paper presented at: American Society of Cataract and Refractive Surgery; San Diego, CA; 2007.
 16. Schallhorn SC, Tanzer DJ. Ideal spherical aberration to optimize visual outcome. Paper presented at: Annual Symposium of the American Society of Cataract and Refractive Surgery; San Diego, CA; April 2007.
 17. Awwad ST, Lehmann JD, McCulley JP, Bowman RW. A comparison of higher order aberrations in eyes implanted with AcrySof IQ SN60WF and AcrySof SN60AT intraocular lenses. *Eur J Ophthalmol.* 2007;17(3):320-326.
 18. Pandita D, Raj SM, Vasavada VA, et al. Contrast sensitivity and glare disability after implantation of AcrySof IQ Natural aspherical intraocular lens: prospective randomized masked clinical trial. *J Cataract Refract Surg.* 2007;33(4):603-610.
 19. 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(3):574-585.
 20. Piers PA, Weeber HA, Artal P, Norrby S. Theoretical comparison of aberration-correcting customized and aspheric intraocular lenses. *J Refract Surg.* 2007;23(4):374-384.
 21. Akkin C, Ozler SA, Menten J. Tilt and decentration of bag-fixated intraocular lenses: a comparative study between capsulorrhexis and envelope techniques. *Doc Ophthalmol.* 1994;87(3):199-209.
 22. Mutlu FM, Bilge AH, Altinsoy HI, Yumusak E. The role of capsulotomy and intraocular lens type on tilt and decentration of polymethylmethacrylate and foldable acrylic lenses. *Ophthalmologica.* 1998;212(6):359-363.
 23. Hayashi K, Harada M, Hayashi H, et al. Decentration and tilt of polymethyl methacrylate, silicone, and acrylic soft intraocular lenses. *Ophthalmology.* 1997;104(5):793-798.