

Peer-Reviewed Literature:

Update on Aspheric IOL Technology



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Spherical aberration is a symmetrical fourth-order aberration. It is a key contributor to the deterioration of retinal image quality as a result of peripheral rays being focused anteriorly to refracted paraxial rays of light. Corneal surface analysis confirms that the prolate corneas of both young and cataract-aged patients have, on average, positive spherical aberration.¹ In youth, the generally negative spherical aberration of the crystalline lens largely neutralizes the average positive spherical aberration of the prolate cornea and thus results in an optimized retinal image.

As the eye ages, it loses this cornea/lens coupling. The crystalline lens grows, becomes rounder, and therefore develops positive spherical aberration itself, which adds to rather than offsets the average positive corneal spherical aberration. Similarly, conventional spherical IOLs, with their equibiconvex or convex-plano design, augment rather than offset positive corneal spherical aberration. Their implantation results in suboptimal visual quality due to increased spherical aberrations with poor point spread and modulation transfer functions (MTFs).²

The goal of aspheric IOLs is to minimize the aforementioned spherical aberrations and optimize image quality and contrast, while minimizing the induction of asymmetrical aberrations (eg, coma) and mitigating adverse effects on the depth of field and relative MTF. The available aspheric IOLs possess varying degrees of negative spherical aberration. Some are designed to offset the average corneal aberration fully (the Tecnis IOL; Advanced Medical Optics, Inc, Santa Ana, CA; $-0.27\mu\text{m}$ spherical aberration [Figure 1]) or partially (the

Acrysof IQ lens; Alcon Laboratories, Inc., Fort Worth, TX; $-0.2\mu\text{m}$ spherical aberration [Figure 2]). In contrast, another IOL (the Sofport AO lens; Bausch & Lomb, Rochester, NY; $0\mu\text{m}$ spherical aberration [Figure 3]) has neither positive nor negative spherical aberration. Clinical and laboratory studies have compared the outcomes in eyes implanted with aspheric IOLs. The following articles were reviewed:

1. Holladay JT, Piers PA, Koranyi G, et al. A new intraocular lens design to spherical aberration in pseudophakic eyes. *J Refract Surg.* 2002;18:683-691.
2. Mester U, Dillinger P, Anterist N. Impact of a modified optic design on visual function: clinical comparative study. *J Cataract Refract Surg.* 2003;29:652-660.
3. Packer M, Fine IH, Hoffman RS, Piers PA. Improved functional vision with a modified prolate intraocular lens. *J Cataract Refract Surg.* 2004;30:986-992.
4. Kershner RM. Retinal image contrast and functional visual performance with aspheric, silicone, and acrylic intraocular lenses. Prospective evaluation. *J Cataract Refract Surg.* 2003;29:1684-1694.
5. Bellucci R, Morselli S, Piers P. Comparison of wavefront aberration and optical quality of eyes implanted with five different intraocular lenses. *J Refract Surg.* 2004;20:297-306.
6. Bellucci R, Scialdone A, Buratto L, et al. Visual quality and contrast sensitivity comparison between Tecnis and AcrySof SA60AT intraocular lenses: a multicenter randomized study. *J Cataract Refract Surg.* 2005;31:712-717.
7. 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.

8. Piers PA. Performance and limitations of customized wavefront-correcting IOLs. *Invest Ophthalmol Vis Sci.* 2006; 47:E-Abstract 320.

9. Marcos S, Barbero S, Jimenez-Alfaro I. Optical quality and depth-of-field of eyes implanted with spherical and aspheric intraocular lenses. *J Refract Surg.* 2005;21:223-235.

10. Piers PA, Fernandez EJ, Manzanera S, et al. Adaptive optics simulation of intraocular lenses with modified spherical aberration. *Invest Ophthalmol Vis Sci.* 2004;45:4601-4610.

11. Artal P, Villegas EA, Alcon E, Benito A. Better than normal visual acuity does not require perfect ocular optics. *Invest Ophthalmol Vis Sci.* 2005;46:E-Abstract 3615.

12. Applegate RA, Marsack JD, Ramos R, Sarver EJ. Interactions between aberrations to improve or reduce visu-

al performance. *J Cataract Refract Surg.* 2003;29:1487-1495.

13. Levy Y, Segal O, Avni I, Zadok D. Ocular higher-order aberrations in eyes with supernormal vision. *Am J Ophthalmol.* 2005; 139:225-228.

14. Amesbury EC, Schallhorn SC. Contrast sensitivity and limits of vision. *Int Ophthalmol Clin.* 2003;43:31-42.

15. Rocha KM, Soriano ES, Chalita MR, et al. Wavefront analysis and contrast sensitivity of aspheric and spherical Intraocular lenses: a prospective study. *Am J Ophthalmol.* In press.

16. Wang L, Santaella RM, Booth M, Koch DD. Higher-order aberrations from the internal optics of the eye. *J Cataract Refract Surg.* 2005;31:1512-1519.

17. Kelly JE, Mihashi T, Howland HC. Compensation of corneal horizontal/vertical astigmatism, lateral coma, and spherical aberration by internal optics of the eye. *J Vis.* 2004;4:262-271.

18. Schwartz DM. Light-adjustable lens. *Trans Am Ophthalmol Soc.* 2003;101:417-436.

FROM THEORY TO LENS

A wavefront eye model was developed using an optical ray-tracing package. Researchers used this tool³ to design a biconvex lens with a modified, aspheric, anterior prolate surface to offset the average positive corneal spherical aberration calculated from the anterior elevation data of a cohort of 71 cataract patients ($Z[4,0] = +0.27 \pm 0.02 \mu\text{m}$). The clinical benefits of this negatively aspheric, silicone IOL (Tecnis Z9000; $Z[4,0] = -0.27 \mu\text{m}$, refractive index of 1.46) are better low-contrast visual acuity and photopic and mesopic contrast sensitivity than achieved with spherical IOLs.²⁻⁶ The Tecnis lens is also available on an acrylic platform (Tecnis ZA9003). Patients in driving simulators who had received the Tecnis lens performed better than those with spherical IOLs, thanks to improved low-contrast and mesopic acuity as well as reduced spherical aberration for the entire eye. As a result, the Centers for Medicaid & Medicare Services conferred New Technology IOL status on the lens.

The decentration of an IOL with negative or positive spherical aberration may induce defocus, astigmatism, and coma, which would degrade the optical transfer function and retinal image quality.⁷ Although the negatively aspheric Tecnis design produces favorable theoretical and clinical results, further investigations have revealed the lens' potential limitations. The decentration of an aspheric IOL with negative spherical aberration produces a hyperopic refractive error along with asymmetric aberrations, whereas an equally decentered spherical IOL produces a myopic shift.

Holladay and colleagues¹ used calculations of the MTF to show that the Tecnis needed to be centered within



Figure 1. The Tecnis IOL.

0.4mm and tilted less than 7° in order to exceed the optical performance of a conventional spherical IOL. Using a polychromatic eye model, Piers⁸ concluded that the Tecnis lens would need to be decentered by 0.8mm or tilted at least 10° before its optical performance would be worse than a spherical IOL of the same power. Although possible in clinical situations where there is compromised zonular or capsular integrity,

there are no reports in the peer-reviewed literature of significant decentration with the Tecnis IOL.

In general, clinical observations of IOL decentration and tilt fall below either of the aforementioned tolerances. Because the cornea, lens, and fovea represent an asymmetric optical system, however, the optical effects of IOL decentration should be determined with reference to the visual axis. Also, in patients with senile miosis, the adverse effects of IOL decentration may be limited, as would the benefit of an aspheric IOL.

Another theoretical limitation of aspheric IOLs regards depth of field. Through an analysis of optical quality met-

rics such as MTF and simulated retinal images, Marcos et al⁹ demonstrated that the through-focus behavior of the Tecnis at lower ranges of defocus ($\pm 0.75D$) was either better than or similar to that of spherical IOLs. With greater negative defocus, however, spherical IOLs performed better. The investigators concluded that eyes achieving BSCVA

with spherical IOLs should perform near tasks better than those achieving BSCVA with aspheric IOLs. Using an adaptive optics simulator in four normal, young patients, Piers et al¹⁰ showed comparable visual performance for defocus as large as $-1.00D$ with both a spherical and an aspheric IOL, however.



Figure 2. The Acrysof IQ lens.

Negatively aspheric IOLs should be used with caution in patients with negative corneal asphericity. In the study by Holladay et al,¹ which led to the design of the Tecnis IOL, a reduction in spherical aberration for the entire eye was estimated to occur in more than 90% of the population. Because the IOL offsets the average amount of corneal spherical aberration, however, it will induce negative spherical aberration in some patients who have highly prolate corneas to begin with. The IOL should also be avoided in patients following hyperopic laser refractive surgery, which incorporates a prolate design into the corneal ablation.

WHAT IS THE OPTIMAL RESIDUAL SPHERICAL ABERRATION?

Researchers have different opinions regarding the optimal, residual, postoperative spherical aberration to target with IOL implantation after phacoemulsification. Some suggest that it should be zero (ie, the idea behind the Tecnis IOL's design) based upon studies in young individuals with excellent vision. For example, Artal et al¹¹ found that subjects under the age of 25 with naturally occurring supervision (20/15 or better) had values of spherical aberration not statistically different from

zero. However, there does not appear to be a correlation between spherical aberration and visual acuity. This may reflect the complex interactions between individual higher-order aberrations that comprise the whole eye wave.¹²

Other investigators see an advantage in leaving slight, residual, positive spherical aberration. They believe that small amounts may mitigate the deleterious effects of isolated aberrations and may play a role in neural processing and adaptation. Levy et al¹³ reported that the whole eye spherical aberration for 70 eyes with a UCVA of 20/15 or better was $+0.11 \pm 0.07 \mu\text{m}$. Amesbury and Schallhorn¹⁴ found that pilots with a UCVA of 20/12.5 or better did not have fewer higher-order aberrations than a young control group without such supernormal vision. Modest amounts of positive spherical aberration may mitigate the adverse effects of chromatic aberration and higher-order monochromatic aberration⁷ and may help patients who were targeted for emmetropia to cope with a postoperatively hyperopic refraction. Spectacle correction can compensate for spherical aberration but cannot correct for asymmetrical aberrations such as coma that may be induced by an IOL with negative spherical aberration that is significantly decentered from the visual axis.



Figure 3. The Sofport AO lens.

NEUTRALITY

Based upon the principle of *primum non nocere*, the Sofport AO (LI61AO; refractive index, 1.43) does not add or subtract spherical aberration. Using ray-tracing software and a pseudophakic eye model, Altmann et al⁷ calculated that the optical performance of this biconvex, silicone lens (which has aspheric anterior and posterior surfaces) is neutral in terms of spherical aberration. Their experimental model showed that the optical performance of the IOL was better than its conventional, spherical counterpart (LI61U; Bausch & Lomb). The former had less spherical aberration and was not affected by decentration. They also found that

the Sofport AO performed better than the Tecnis lens when decentration exceeded 0.15, 0.30, or 0.38mm with 3-, 4-, or 5-mm pupils, respectively. Decentration of the Sofport IOL also had a less negative impact on depth of field or defocus.

The results from a multicenter trial comparing the clinical efficacy of the Sofport AO and Tecnis IOLs are pending.

A PARTIAL CORRECTION OF SPHERICAL ABERRATION

The Acrysof IQ lens (refractive index, 1.55) is a single-piece, hydrophobic, acrylic IOL with a modified posterior surface design. The Acrysof platform allows for a thinner central optic than comparable aspheric IOLs (data on file with Alcon Laboratories, Inc.). The Acrysof IQ lens is the only aspheric IOL that incorporates blue-light-filtering properties and has been shown to produce less spherical aberration and higher contrast sensitivity under mesopic conditions than the original Acrysof IOL.¹⁵ The design of this lens is based upon the finding by several investigators^{16,17} that the mean value of the internal spherical aberration of young subjects ranges from -0.1 to -0.3 μ m.

The Acrysof IQ IOL is designed to bring the average pseudophakic eye to a slightly positive targeted spherical aberration (approximately +0.07 μ m), with a resultant improvement in night-driving-simulation results compared with a conventional monofocal lens (data on file with Alcon Laboratories, Inc.). The Centers for Medicare & Medicaid Services have granted the Acrysof IQ lens New Technology IOL status. Additional investigations are needed to compare the clinical performance of this and other aspheric IOLs and to determine whether the Acrysof IQ lens induces asymmetrical higher-order aberrations if decentered.

Both the Acrysof IQ and the Tecnis ZA9003 are acrylic, whereas the Sofport AO and Tecnis Z9000 lenses are made of second-generation silicone. Acrylic IOLs may offer advantages in patients who are at high risk of future retinal surgery with silicone oil, such as those with diabetic retinopathy or high myopia. A potential future alternative to currently available aspheric IOLs is a wavefront-optimized, light-adjustable IOL (Calhoun Vision, Inc., Pasadena, CA),¹⁸ which might compensate for symmetrical and asymmetrical corneal aberrations via postimplantation adjustment.

BOTTOM LINE

Well-centered aspheric IOLs have been shown to improve optical performance and contrast sensitivity compared with conventional spherical IOLs. The FDA has accepted clinical data supporting the labeling of the Tecnis lens for improved functional vision that is likely to provide a meaningful safety benefit to elderly drivers. Surgeons should exercise caution when implanting negatively aspher-

ic IOLs in the sulcus or in clinical situations that may increase the risk of IOL decentration (eg, a compromised capsule or zonules, corectopia, a large capsulorhexis, or asymmetrical capsular coverage). Decentration may lead to more marked degradation of image quality and a decrease in optical transfer function as compared with an equally decentered Sofport AO IOL or even a conventional IOL.

By importing elevation topographic maps into commercially available software such as Vol-CT (Sarver and Associates; Carbondale, IL) or using topographers that directly derive corneal wavefront measurements, the ophthalmologist can select the optimal aspheric IOL for each pseudophakic eye. Surgeons can target a small amount of residual, positive spherical aberration or no residual spherical aberration. For example, the Sofport AO lens may be most appropriate in a patient with highly asymmetrical corneal aberrations (eg, forme fruste pellucid marginal degeneration or keratoconus), because it will not induce additional higher-order aberrations. Preoperative testing should include pupillometry under mesopic or scotopic conditions, because a small pupil may reduce the impact and advantages of an aspheric IOL on the visual performance of older patients. ■

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