

WHY WE SHOULD TAILOR THE ASPHERICITY OF MONOFOCAL IOLS TO EACH EYE



An overview of the concepts and evidence supporting this approach.

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One of the most important discoveries affecting our understanding of human visual optics¹ (and subsequently IOL design²) was that the youthful eye's crystalline lens offsets the spherical aberration (SA) of the cornea,^{1,3,4} which averages +0.27 μm .⁵ The two are uncoupled later in life as the lens ages,⁶ which is a component of dysfunctional lens syndrome.⁷ The lens loses some of its offsetting negative SA as it thickens and changes in shape. As this unmasking of inherent corneal SA proceeds, image quality generally degrades due in part to an increase in SA. This effect, along with an age-related decrease in mean pupillary size, increases depth of focus via pseudoaccommodative mechanisms.

IMPACT OF SA

We surgeons have a number of aspheric monofocal IOLs at our disposal that fully or partially offset the average SA of the cornea. IOLs that produce no aberrations (eg, zero-aberration aspheric IOLs) are also available. Healthy, unoperated corneas have a range of corneal SAs. An even broader spectrum of positive and negative SAs is present in eyes that have undergone keratorefractive procedures such as myopic and hyperopic LASIK and PRK.

How can we take advantage of aspheric monofocal IOLs as we seek to customize visual performance and outcomes to meet the needs of each patient? Are there special circumstances in which customization may be particularly beneficial? Finally, can we use this approach to selectively enhance

image quality by minimizing ocular SA, for example in the dominant eye, and increasing SA and depth of focus in the nondominant eye? Adaptive optics simulations of increases in positive or negative SA have demonstrated a 2.00 D enhancement of depth of focus.⁸

SUPPORTING EVIDENCE

A meta-analysis of spherical versus aspheric IOLs showed better contrast sensitivity with the latter at all spatial frequencies, most conspicuously under mesopic conditions and with pupillary sizes of 4 mm or greater, as well as reduced overall ocular SA.⁹ Studies in which one eye was randomly assigned to a spherical IOL and the other to an aspheric IOL have confirmed these findings for IOLs that partially¹⁰ or fully¹¹ compensate for average corneal SA as well as for zero-aberration IOLs.¹² Additionally, patients in the FDA-monitored, randomized, double-masked night-driving simulation study of the Tecnis IOL (Johnson & Johnson Vision), an IOL with an SA offset of -0.27 μm , performed functionally better in 20 of 24 driving conditions (and statistically better in 10 conditions) when relying on the BCVA of the Tecnis eye versus the eye that received an AcrySof spherical IOL (Alcon).¹³

Some studies in patients of cataract age without corneal disease or a history of keratorefractive surgery have shown a wide range of corneal SAs, generally measured at the 6-mm optical zone (eg, +0.076 to +0.544 μm ¹⁴). Given this range, several researchers have examined whether individualizing the specific

aspheric monofocal IOL with respect to the eye's inherent corneal SA improves visual performance. Based upon the corneal wavefront measurement of SA, Packer et al customized selection between a Tecnis aspheric monofocal IOL (Johnson & Johnson Vision) with an SA of -0.27 μm , an AcrySof IQ (Alcon) with an SA of -0.2 μm , and a SofPort AO (Bausch + Lomb) with an SA of 0 μm SA. A mean total ocular SA of -0.013 \pm 0.072 μm was achieved, and 93% of eyes had less than \pm 0.10 μm of total ocular SA.¹⁵ Studies using other aspheric IOLs extended these findings to include better mesopic contrast sensitivity, a higher modulation transfer function cutoff, and lower ocular SA with customization.^{16,17} These benefits may be even greater in patients with large pupils under mesopic conditions with or without glare.¹⁸

In a recent study, normal eyes were randomly assigned to receive either an aberration-free IOL (enVista, Bausch + Lomb) or a negative spherical aberration IOL (Tecnis, -0.27 μm) without customized selection for preexisting corneal SA. The group with an aberration-free IOL had a flatter defocus curve, better distance-corrected near visual acuity, and higher total SA.¹⁹ These findings may support a strategy of customizing the choice of aspheric IOL to reduce SA if the goal is to maximize image quality in the operative eye or to preserve ocular SA if the goal is to enhance depth of focus.

ASPHERIC MONOFOCAL IOL CHOICE

Eyes that have undergone keratorefractive

surgery warrant special consideration. The corneas have different powers across varying optical zones and have altered amounts of corneal SA. Wang and colleagues sought to determine the optimal amount of SA in an IOL to maximize optical quality after myopic PRK.²⁰ The investigators simulated aspheric IOL implantation in 102 eyes. Mean fourth-order SA was $0.47 \pm 0.163 \mu\text{m}$ at the 6-mm optical zone (range, -0.044 to $0.831 \mu\text{m}$), whereas mean fourth-order SA in unoperated corneas is $0.27 \mu\text{m}$. Although the optimal amount of SA for image quality varied in the PRK eyes depending on the residual refractive error and the entire corneal wave, the best image quality was generally achieved with an IOL that corrected negative SA.

In a theoretical simulation study, Wang et al sought to determine the optimal amount of SA in IOLs to maximize optical quality in eyes that had undergone hyperopic corneal surgery.²¹ Mean corneal SA at a 6-mm optical zone was $-0.114 \pm 0.239 \mu\text{m}$ (range, -0.876 to $0.320 \mu\text{m}$). The wavefront profile was more complex with elevated third- and fifth-order aberrations, suggesting that an IOL with zero asphericity might be optimal in terms of the entire ocular wavefront. A prospective study by Rocha and colleagues¹⁹ assessed outcomes with aspheric monofocal IOLs in patients who had undergone hyperopic LASIK compared to those with unoperated corneas. The post-LASIK cohort had significantly greater negative corneal asphericity ($0.74 \mu\text{m}$ hyperprolate vs $0.35 \mu\text{m}$ in normal corneas) and significantly greater negative SA ($-0.22 \mu\text{m}$) than the surgically naïve corneas ($+0.34 \mu\text{m}$, $P < .001$). The hyperprolate corneas were also found to have greater subjective depth of focus (flatter defocus curve) and significantly better distance-corrected near visual acuity (20/30.4) than eyes with normal corneas (20/39) when implanted with aberration-free IOLs.

LIMITATIONS AND OPPORTUNITIES

We are entering an age in which adaptive optics can take into account the whole-eye wavefront, pupillary size, targeted refractive error (lower-order aberrations), and at least a short-term neural adaptive component to determine each eye's optimal SA across an entire defocus curve. Except in the case of dense cataracts, such testing can be performed preoperatively, allowing more accurate correction of distance, intermediate, and near vision and image quality or overall depth of focus.²² The optimal SA will depend on the entire ocular wavefront and the interaction of SA with other higher-order aberrations as well as residual ametropia from the targeted refractive outcome.

Although we have not yet reached the lofty refractive outcomes of LASIK with modern cataract surgery, the latest IOL formulas, intraoperative aberrometry, AI, and machine learning are iteratively improving our ability to achieve the target refraction. The Light Adjustable Lens (RxSight) has brought this targeting ability to a new level and should, in the future, allow the customization of SA,²³ either directly during light adjustment or through the choice of an initial refractive target and indirect customization of SA with the direction of the adjustment (plus or minus defocus).

With advances toward an implantable refractive IOL capsule and modular IOL designs,²⁴ in the future, it may be easy to replace the IOL optic or adjust the effective lens position instead of performing an IOL exchange. This paradigm may afford additional means of postoperatively adjusting SA and other parameters. Finally, femtosecond laser-assisted refractive index shaping of either the cornea²⁵ or IOL optic²⁶ may ultimately permit a less invasive postoperative adjustment of both higher- and lower-order aberrations. ■

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