The Fundamentals of Spherical Aberration

Fifteen pearls every cataract surgeon should know.

BY GEORGE H.H. BEIKO, BM, BCh, FRCSC

Pearl No. 1: The wavefront characteristics of light can be described in mathematical terms using different systems, including Zernike polynomials and Fourier analysis. Using Zernike polynomials, sphere (defocus) and cylinder (astigmatism) describe the two higher-order aberrations (HOAs) that we measure with phoropters. These aberrations account for approximately 83% of the magnitude of the wavefront of light. Spherical aberration and coma are the next most significant HOAs. Spherical aberration describes the amount of bending that occurs as light passes through a refracting surface, such as the cornea, and compares the relative position of the focal points for the peripheral and central light beams. Positive spherical aberration occurs when the peripheral rays are focused in front of the central rays; this value is expressed in microns.

Pearl No. 2: The wavefront of the human eye can be measured using wavefront analyzers such as Shack-Hartmann systems and Tracey aberrometers (iTRACE; Tracey Technologies, Corp.). Corneal topographers can measure the front surface of the cornea (Figure 1), and this data can be transformed to determine the HOAs of the cornea. By convention, corneal spherical aberration is measured at 6 mm.[1]

Pearl No. 3: In the human eye, HOAs come primarily from the anterior corneal surface and the lens; other sources are the posterior corneal surface and the retina. In an aphakic eye, the anterior corneal surface accounts for 98% of wavefront changes. Small-incision (less than 2.8 mm) cataract surgery causes minimal changes in the spherical aberration of the eye and, for practical terms, can be considered to have no effect.[2]

TAKE-HOME MESSAGE

- Sphere and cylinder account for approximately 83% of the magnitude of the wavefront of light.
- By convention, corneal spherical aberration is measured at 6 mm.
- Surgeons should first optimize their formulas for IOL power calculation before adjusting spherical aberration.
- Common aspheric IOLs correct the average theoretical corneal spherical aberration, the average measured corneal spherical aberration, or do not influence it.

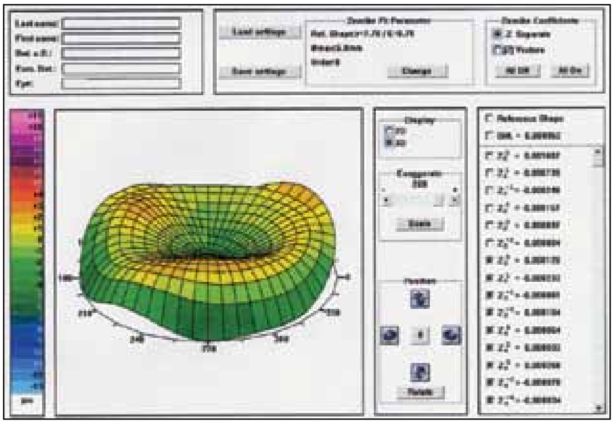

Figure 1. Wavefront data derived from corneal topography, using Easygraph (Oculus).

Pearl No. 4: Measurements of spherical aberrations of the anterior corneal surface have found the average value to be 0.27 µm with a large standard deviation of 0.10 µm. Due to this variation, the value should be measured for each individual patient.[3]

Pearl No. 5: The presence of spherical aberrations can cause glare and halo around lights. The greater the degree of spherical aberration, the greater amount of halo that is induced (Figure 2).

Pearl No. 6: In cataract surgery, targeting emmetropia has a greater effect on Snellen acuity outcome than manipulating spherical aberration. Thus, surgeons should first optimize their formulas for IOL power calculation before adjusting spherical aberration. Aspheric IOLs improve the quality of vision by providing greater contrast sensitivity, not by increasing Snellen acuity. An increase in spherical aberration away from 0.00 causes a decrease in contrast sensitivity.[4]

Pearl No. 7: Using aspheric IOLs improves driving safety due to improved contrast sensitivity. This is

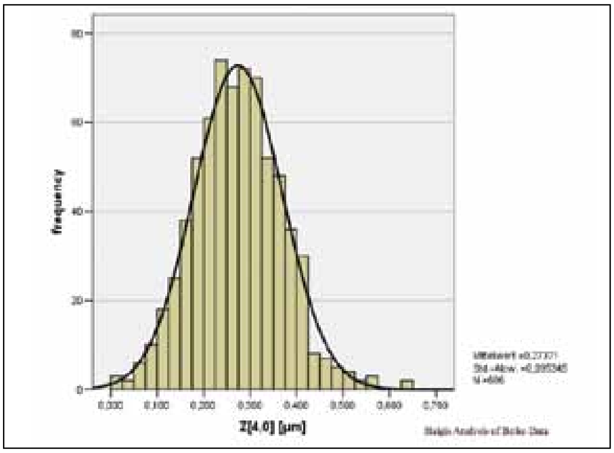

Figure 2. Normal distribution of corneal spherical aberration.[3]

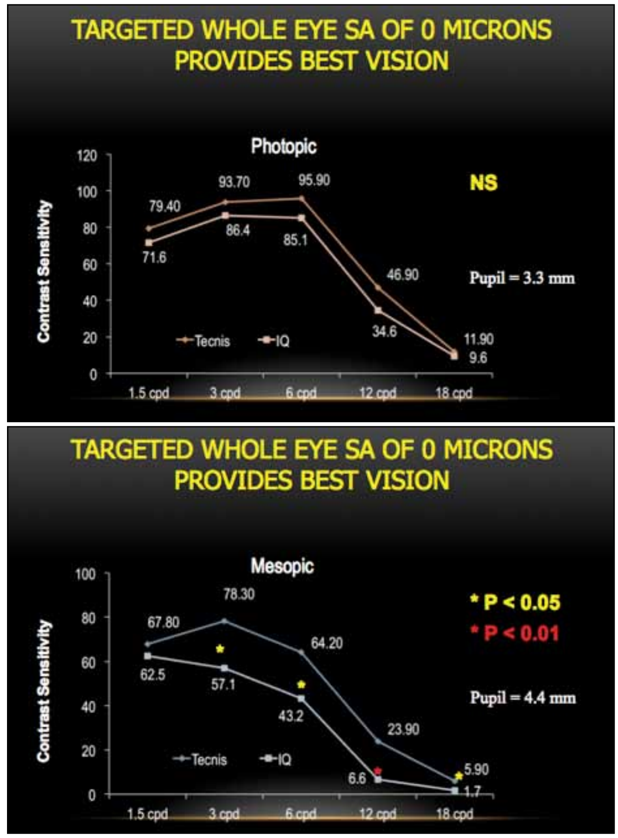

Figure 3. Comparison of contrast sensitivity for patients with 0.27 µm of measured corneal spherical aberration randomized to Tecnis (Abbott Medical Optics Inc.) and AcrySof IQ (Alcon Laboratories, Inc.) under photopic and mesopic conditions.[6]

particularly evident on nighttime simulation testing, in which up to a 45-foot advantage in stopping distance at 55 mph (88.51 km/hr) can be achieved.[5]

Pearl No. 8: The impact of spherical aberration is dependent on pupil size. For practical purposes, spherical aberration comes into play when pupils are greater than 4 mm; thus, it has the most impact under mesopic or scotopic conditions and in younger patients. Older individuals may have large pupils, so pupils should be measured for each patient if aspheric IOLs are to be used.

Pearl No. 9: The clearest image is provided when the total spherical aberration value for the eye is 0.00. Most of the effect of targeting this value is seen in nighttime lighting conditions (Figure 3).[6]

Pearl No. 10: Refractive error can compensate for residual spherical aberration. Positive spherical aberration causes a myopic shift, and negative spherical aberration causes a hyperopic shift in refraction. Although refractive error is independent of pupil size, spherical aberration is dependent on pupil size; for small pupils, it can be negligible, but for larger pupils it is significant in its effect. Thus, refractive error will compensate for spherical aberration at larger pupil sizes but will introduce defocus at smaller pupil sizes (Figure 4). This information can be used to customize results for individual patients based on the choice of aspheric IOL.[7]

Pearl No. 11: Incisional corneal surgery for astigmatism correction has minimal effect on spherical aberration.

Pearl No. 12: Negative aspheric IOLs have a slightly higher power centrally. For a 20.00 D lens, this power can be 0.50 D greater and, thus, provides some pseudoaccommodative effect. This is one explanation for increased near vision in patients implanted with aspheric IOLs.

Pearl No. 13: Corneal spherical aberration and Q value are not the same thing. Spherical aberration describes how a wavefront deviates from the ideal after passing through a refracting surface. In actuality, it is a measure of the effect a surface has on light and is measured in microns. The Q value describes the refracting surface and is a measure of the shape of a surface; it has no units. The shape of a surface does affect spherical aberration. An ideal spherical surface has a Q value of 0.00. A prolate surface has a negative Q value; a parabola is a prolate surface that eliminates all spherical aberration and has a Q value of -0.50. The human cornea has an average Q value of -0.26; it would require a value of -0.52 to eliminate all spherical aberration. The Q value of a young adult crystalline lens is -0.25; thus, the combined value for a young phakic eye results in elimination of spherical aberration. As the lens ages, the Q value changes, and after age 40 is 0.00. With a perfect single refracting surface such as an ellipse, keratometry and Q value could be used to calculate the spherical aberration of that surface. For a corneal Q value of -0.26 and average keratometry of 44.00 D, the calculated spherical aberration is 0.18 µm. The average measured spherical aberration of the cornea is 0.27 µm because the cornea has a complex surface that is

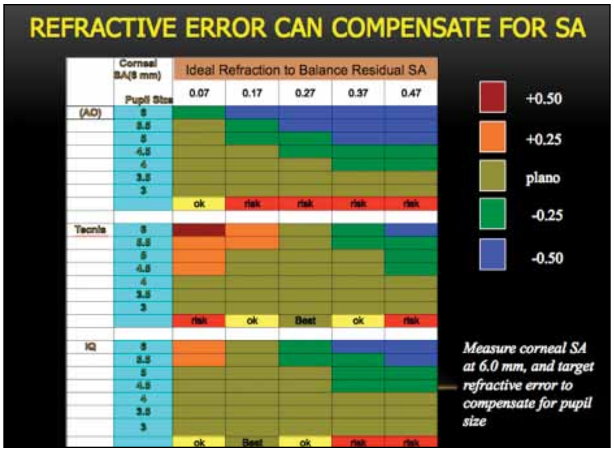

Figure 4. Nomogram for targeting refractive error to balance residual spherical aberration after adjusting for pupil size.[7]

steeper centrally. Common aspheric IOLs correct the average theoretical corneal spherical aberration, the average measured corneal spherical aberration, or do not influence it.

Pearl No. 14: Tilt and decentration affect the performance of aspheric IOLs. Aspheric lenses must be decentered more than 0.8 mm and tilted more than 10° before all effect is lost.[8]

Pearl No. 15: Leaving spherical aberration (positive or negative) in the optical system improves depth of focus, but at the cost of loss of contrast vision. Current strategies involve targeting up to -0.30 to -0.40 µm of spherical aberration in one eye, so as to increase depth of focus without significantly affecting Snellen acuity. ■

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1. Barbero S, Marcos S, Merayo-Lloves L, Moreno-Barriuso E. Validation of the estimation of corneal aberrations from videokeratography in keratoconus. *J Refract Surg*. 2002;18:263-270.
2. Guirao A, Tejedor J, Artal P. Corneal aberrations before and after small-incision cataract surgery. *Invest Ophthalmol Vis Sci*. 2004;45:4312-4319.
3. Beiko GHH, Haigis W, Steinmueller A. Distribution of the corneal spherical aberration in a comprehensive ophthalmology practice, and can keratometry be predictive of the value of the corneal spherical aberration? *J Cataract Refract Surg*. 2007;33(5):848-858.
4. Pesudovs K. Meta-analysis of studies comparing wavefront aberration and visual performance of spherical and aspheric intraocular lenses. Paper presented at: ESCRS; September 2008; Berlin.
5. Data on file. TECNIS package insert. April 2004. AMO. Santa Ana, California.
6. Beiko GHH. Targeting spherical aberration correction in cataract surgery: comparison of 0.00 and 0.10 microns. Paper presented at: the ASCRS Annual Meeting; April 4-9, 2008; Chicago.
7. Beiko GHH, Zhao H. Normogram for aspheric IOL implantation based on pupil size, corneal asphericity and target refraction. Paper presented at: the ASCRS Annual Meeting; April 4-9, 2008; Chicago.
8. Piers PA, Tabernero J, Benito A, et al. Optical and visual performance are well correlated in pseudophakic eyes. Paper presented at: ASCRS Symposium on Cataract, IOL and Refractive Surgery; April 16, 2005; Washington, DC.