

Aspheric intraocular lens selection: the evolution of refractive cataract surgery

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In the current era of presbyopia-correcting intraocular lenses (IOLs), toric IOLs and aspheric IOL technology, the practice milieu is changing. Informed consent takes on new meaning when the surgeon and the patient decide together which IOL technology represents the best fit for a particular life style and its visual demands. Customizing IOL choice is no longer optional; it is essential to the practice of refractive lens surgery.

The positive spherical aberration of a spherical pseudophakic IOL tends to increase total optical aberrations, so attention has turned to the development of aspheric IOLs [1]. These designs are intended to reduce or eliminate the spherical aberration of the eye and improve functional vision as compared with a spherical pseudophakic implant. Three aspheric IOL designs are currently marketed in the USA: the Tecnis Z9000/2/3 IOL (AMO, Santa Ana, California, USA), the AcrySof IQ IOL (Alcon, Fort Worth, Texas, USA) and the SofPort AO IOL (Bausch & Lomb, San Dimas, California, USA). Other aspheric IOL designs not yet available in the USA also show promise for the reduction of spherical aberration [2].

The Tecnis IOL was designed with a modified prolate anterior surface to compensate for the average corneal spherical aberration found in the adult eye. It introduces $-0.27 \mu\text{m}$ of spherical aberration to the eye measured at the 6 mm optical zone. The clinical investigation of the Tecnis IOL submitted to the US Food and Drug Administration (FDA) demonstrated elimination of mean spherical aberration as well as significant improvement in functional vision when compared with a standard spherical IOL [3].

The AcrySof IQ shares the ultraviolet- and blue-light-filtering chromophores found in the single-piece acrylic AcrySof Natural IOL. The special feature of the AcrySof IQ IOL is the posterior aspheric surface designed to reduce spherical aberration by addressing the effects of over-refraction at the periphery. It adds $-0.20 \mu\text{m}$ of

spherical aberration to the eye at the 6 mm optical zone. The SofPort Advanced Optics (LI61AO) IOL is an aspheric IOL that has been specifically designed with zero spherical aberration so that it will not contribute to any preexisting higher-order aberrations.

Multiple peer-reviewed, prospective, randomized scientific publications [4–13] have demonstrated reduction or elimination of spherical aberration with the Tecnis modified prolate IOL when compared with a variety of spherical IOLs. Data show that the mean spherical aberration in the eyes implanted with the Tecnis IOL is, in the words approved by the FDA, ‘not different from zero’. Studies have also documented superior functional vision with the Tecnis IOL. Subjects in the FDA-monitored randomized double-masked night driving simulation study of the Tecnis IOL performed functionally better in 20 of 24 driving conditions (and statistically better in 10 conditions) when using best-spectacle correction with the eye implanted with the Tecnis IOL, as compared to best-spectacle correction with the eye implanted with the AcrySof spherical IOL [2]. Data from the night driving simulation showed a significant correlation between reduction of spherical aberration and detection distance for the pedestrian target under rural conditions with glare (the most difficult target to discern).

More recently, peer-reviewed published clinical studies [14–17] have also supported reduction of spherical aberration and superior functional vision with the AcrySof IQ when compared with spherical IOLs. In fact, the optical advantages of aspheric IOL technology have become fairly well accepted although some controversy remains in the areas of functional benefit as it relates to pupil size, IOL decentration, depth of focus and customization [18]. Some studies [12,13] have shown little or no benefit of aspheric IOLs with smaller pupils while one laboratory study [19] showed that the SofPort AO provides better optical quality than either a negatively aspheric or a spherical IOL under conditions of significant decentration. One study [17] has shown diminished distance-corrected near visual acuity, a surrogate measure for depth of focus, with the AcrySof IQ aspheric IOL as compared to the AcrySof SN60AT spherical IOL.

Regarding customization of the aspheric correction, it has been suggested that achieving zero total spherical aberration postoperatively provides the best quality of vision.

Piers and coauthors [20] utilized an adaptive optics simulator to assess letter acuity and contrast sensitivity for two different values of spherical aberration. The first condition was the average amount of spherical aberration measured in pseudophakic patients with spherical IOLs. The second condition represented the complete correction of the individual's spherical aberration ($Z[4,0]=0$). The researchers found an average improvement in visual acuity associated with the correction of spherical aberration of 10 and 38% measured in white and green light, respectively. Similarly, average contrast-sensitivity measurements improved 32 and 57% in white and green light. When spherical aberration was corrected, visual performance was as good as or better than for the normal spherical aberration case for defocus as large as ± 1 D. Therefore, these researchers concluded that completely correcting ocular spherical aberration improves spatial vision in the best-focus position without compromising the subjective tolerance to defocus [20].

On the other hand, it has alternatively been suggested that providing $Z[4,0]=+0.1\ \mu\text{m}$ of postoperative spherical aberration represents a better choice [21]. This line of reasoning originated from a study [22] demonstrating that 35 young subjects with uncorrected visual acuity of 20/15 or better had a mean total spherical aberration of $Z[4,0]=+0.110\pm 0.077\ \mu\text{m}$. There is no logical basis, however, to infer that the spherical aberration is responsible for the supernormal visual acuity. In fact, the authors of this study concluded that 'The amount of ocular HOAs [higher-order aberrations] in eyes with natural supernormal vision is not negligible, and is comparable to the reported amount of HOAs in myopic eyes' [22]. This conclusion is born out by a study performed by Wang and Koch [23] demonstrating a mean total spherical aberration of $Z[4,0]=+0.128\pm 0.074\ \mu\text{m}$ in a series of 532 eyes of 306 subjects presenting for refractive surgery. Nevertheless, Beiko [21] used the Easygraph corneal topographer (Oculus, Lynnwood, Washington, USA) to select patients with corneal spherical aberration of $+0.37\ \mu\text{m}$, thus targeting a postoperative total ocular spherical aberration of $+0.10\ \mu\text{m}$ following implantation of the Tecnis IOL with $-0.27\ \mu\text{m}$ (the Easygraph includes an optional software package that provides Zernike analysis). The selected patient group demonstrated significantly better contrast sensitivity than an unselected group of control patients under both mesopic and photopic conditions.

Recently, Beiko *et al.* [24] presented data from a series of 696 eyes confirming the mean corneal spherical aberration of $+0.27\ \mu\text{m}$ used in the design of the Tecnis IOL. They found a wide standard deviation of $0.089\ \mu\text{m}$, with a range from $+0.041$ to $+0.632\ \mu\text{m}$, and significantly different corneal spherical aberration means in men and women. In some cases the corneal spherical aberration

differed significantly between fellow eyes. The authors concluded that 'individuals should be measured to determine their unique value when considering correction of this aberration' [24]. In addition, they noted that keratometry and the corneal Q value do not correlate well with spherical aberration, and that therefore corneal spherical aberration must be measured directly with a topographer.

One method of proceeding with customized selection of aspheric IOLs involves the following protocol:

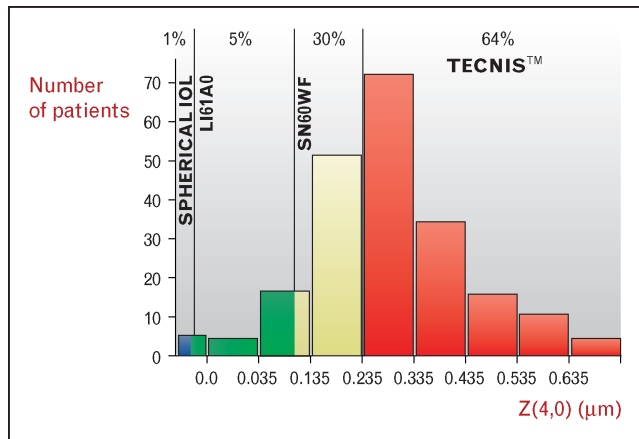
- (1) preoperative testing to include corneal topography as well as axial length determination, anterior chamber depth, phakic lens thickness and corneal white-to-white diameter;
- (2) application of a software package such as VOL-CT (Sarver and Associates, Carbondale, Illinois, USA) to transform the topography elevation data into preoperative corneal Zernike coefficients, with special attention to $Z[4,0]$ fourth-order spherical aberration at the 6 mm optical zone;
- (3) application of an IOL calculation formula, such as the Holladay 2 (available as part of the Holladay IOL Consultant & Surgical Outcomes Assessment Program, Jack T. Holladay, Houston, Texas, USA) to determine correct IOL power for the desired postoperative spherical equivalent;
- (4) determination of desired postoperative total ocular spherical aberration and selection of IOL type.

For example, if the desired postoperative total ocular spherical aberration is zero and the preoperative corneal spherical aberration measures about $+0.27\ \mu\text{m}$, the Tecnis IOL with $-0.27\ \mu\text{m}$ would be selected. In general, the aspheric IOL that comes closest to providing the desired correction should be selected (Fig. 1).

Initial results of customizing the selection of aspheric IOLs have shown promise. In a series of 18 eyes of 12 patients with a mean preoperative corneal spherical aberration of $+0.24\pm 0.075\ \mu\text{m}$ and a targeted postoperative total spherical aberration of $Z[4,0]=0$, the Tecnis IOL was selected for 10 eyes, the AcrySof IQ for seven eyes and the SofPort AO for one eye. The overall mean postoperative total spherical aberration measured $-0.0065\pm 0.060\ \mu\text{m}$, which is statistically not different from zero ($P=0.65$). For the Tecnis group, mean $Z[4,0]=-0.019\pm 0.061\ \mu\text{m}$; for the AcrySof group mean $Z[4,0]=0.0073\pm 0.063\ \mu\text{m}$; for the SofPort eye $Z[4,0]=0.025\ \mu\text{m}$.

In order to determine the feasibility of correcting preoperative corneal spherical aberration, we calculated the mean absolute error for each type of IOL. The mean absolute error is equal to the absolute value of the differ-

Figure 1 Chart for customized selection of aspheric intraocular lenses



Based on a targeted final postoperative spherical aberration of zero, the chart shows the recommended aspheric lens for a range of preoperative corneal spherical aberration measurements at the 6 mm zone and the theoretical frequency with which these values occur in a broad section of the population. IOL, intraocular lens.

ence between the predicted total postoperative spherical aberration and the measured postoperative spherical aberration. The predicted postoperative spherical aberration is simply the preoperative corneal spherical aberration at the 6 mm zone plus the spherical aberration of the IOL implanted. In evaluating the results, allowance should be made for surgically induced spherical aberration; an accepted value for this quantity is $0.03 \pm 0.17 \mu\text{m}$ [25]. The surgically induced spherical aberration represents an estimate of the degree of variation that one should expect in the postoperative Z[4,0] wavefront.

In the Tecnis group, the calculated mean absolute error was $0.052 \pm 0.044 \mu\text{m}$; in the AcrySof group the mean absolute error was $0.052 \pm 0.033 \mu\text{m}$; for the SofPort AO eye the absolute error was $0.040 \mu\text{m}$. The overall mean absolute error for all IOLs was $0.052 \pm 0.038 \mu\text{m}$. There were no statistically significant differences in the mean absolute error among the different groups or between any group and the entire group.

Our results indicate that targeted postoperative spherical aberration can be achieved within a range very close to the limits of surgically induced spherical aberration. Future directions for research include expansion of this initial study and consideration of psychophysical measures such as contrast sensitivity to elucidate the real value of eliminating spherical aberration. It is important to realize that these psychophysical tests of functional vision are generally performed with best-spectacle correction in order to exclude the effects of blur from test results. The ability to achieve superior functional vision with best-spectacle correction reflects both the strength and

weakness of wavefront-corrected IOLs. Given the state of the art of biometry and IOL power calculation it is not possible to achieve precise emmetropia in all eyes. Many pseudophakic patients find that their uncorrected vision is adequate for most tasks of daily living and therefore do not wear spectacles. The amount of defocus and astigmatism they accept may negate the pseudophakic correction of their spherical aberration. Nio *et al.* [26] noted in 2002, 'Both spherical and irregular aberrations increase the depth of focus, but decrease the modulation transfer at high spatial frequencies at optimum focus. These aberrations, therefore, play an important role in the balance between acuity and depth of focus'. For some patients with adequate uncorrected distance acuity, the advantages of a bit more depth of focus may be worth a little loss of contrast. The ultimate expression of this trend is embodied in the multifocal IOL, which by its design reduces optical quality in order to enhance spectacle independence. The Tecnis Multifocal IOL, now in FDA-monitored clinical trials, represents a conscious compromise between optical efficiency and functional vision on the one hand, and quality of life on the other.

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