Resbyopia-correcting intraocular lenses (IOLs) have revolutionized refractive cataract surgery as evolution in materials and optical designs allowed for a better balance of functionality while reducing unwanted symptoms. Presbyopia-correcting IOLs have become a focus of attention in IOL selection discussions with patients due to the increasing number of activities that require near and intermediate vision in our modern world, such as tablets, smartphones, and computers. Numerous IOL platforms have been designed to extend the range of focus as “presbyopia-correcting IOL” options, and three main categories can be identified: those including multifocality (functional bifocal and trifocal IOLs), accommodative or pseudoaccommodative IOLs, and extended depth of focus (EDF) IOLs. Regardless of the optical design or strategy chosen to achieve relative spectacle independence, a certain degree of visual compromise can still be anticipated.

MULTIFOCAL AND ACCOMMODATING STRATEGIES

Multifocal diffractive and/or refractive designs, whether bifocal or trifocal, aim to focus an image onto more than one focal plane. Although the add powers of diffractive IOLs have decreased over the years in an attempt to improve night vision symptoms, there is some degree of contrast sensitivity loss as a result of the light split differential inherent to the mechanism of action.

In theory, accommodative IOL designs enhance defocus at near and intermediate distances by changing the optical power of the eye. Theoretically, this can be achieved by either forward-backward axial movement or flexibility in lens thickness or shape. A potential compromise with accommodating lenses is that current available technologies do not deliver enough “accommodation” to provide near vision functionality. Capsular fibrosis can affect the presbyopia-correcting abilities and the aging ciliary muscle may not have the strength or the mechanical force required to entirely power current lenses. Posterior capsular opacification and capsular contraction resulting in asymmetric vaulting and lens tilt have been reported with the AT-45 Crystalens (Eyeonics Vision, Alisa Viejo, CA) and 1CU IOL (HumanOptics, Erlangen, Germany).

EDF STRATEGIES

During the past two decades, multiple strategies have been used to extend the depth of focus at both the cornea and lens plane. In July 2016, the U.S. Food and Drug Administration approved the first IOL with labeling for EDF (Symfony; Abbott Medical Optics, Inc., Abbott Park, IL). As a result, the opportunity to characterize EDF technologies exists, both optically and clinically. Most recently, the American Academy of Ophthalmology Task Force Consensus Statement defined the minimum performance criteria to categorize any device as an EDF IOL.

The key criteria for EDF IOLs were described as follows:

1. The EDF IOL group should demonstrate comparable monocular mean corrected distance visual acuity to the monofocal controls.
2. The monocular depth of focus curves for the EDF IOLs should be at least 0.50 diopters (D) greater than the depth of focus for the monofocal IOL controls at 0.2 logMAR (20/32 Snellen).
3. The mean (logMAR) monocular distance-corrected intermediate visual acuity (DCIVA) needs to be tested under photopic conditions at 66 cm at 6 months and should demonstrate statistical superiority over the control (one-sided test using significance of .025).
4. At least 50% of eyes achieving monocular DCIVA of 0.2 logMAR (20/32 Snellen) or better at 66 cm.
5. ANSI/ISO-compliant visual acuity charts should have a recommended nominal luminance of 85 cd/m² (80 to 100 cd/m²).

6. A monocular defocus curve should be obtained by using the corrected distance refraction and measuring the visual acuity between +1.50 and -2.50 D in 0.50-D defocus steps, except in the region from +0.50 D through -0.50 D, which should be done in 0.25-D steps.

7. The defocus curve data should be stratified according to the patients’ pupil size and axial length.

8. The mesopic contrast sensitivity function should be performed at 1.5, 3.0, and 6.0 spatial frequencies and 12.0 cycles/degree.

The EDF IOL (Symphony) concept aims to create an elongated focus to enhance intermediate and near visual performance while minimally affecting distance performance. Spatial frequency, pupil size, and ISO corneal models should all be taken into consideration when evaluating diffractive IOL performance in vitro, particularly through-focus modulation transfer function curves. Results obtained on optical benches using a single wavelength and well-centered scenarios are not necessarily achieved in real-life conditions. Thus, lenses should be analyzed under polychromatic light, different pupil apertures, and at various levels of tilt and decentration.

Correlating optical bench performance and clinical performance is still challenging. EDF IOLs are designed to provide less glare and halos and less contrast sensitivity loss when compared to bifocal and trifocal IOLs. However, patients should be counseled about possible dysphotopsias and the need for low power reading glasses postoperatively.

**EDF USING SPHERICAL ABBERRATION DESIGN**

Although the new EDF IOL design has captured the attention of our profession, the concept of EDF is not new. In fact, some of our original spherical IOL designs and monovision strategies also function well in this regard.

The concept of EDF with IOLs was described more than two decades ago. Nakazawa and Ohtsuki reported apparent accommodation of approximately 2.00 D in 39 eyes implanted with spherical IOLs in 1984. The authors also measured each patient’s pupillary diameter, anterior chamber depth, and corneal refractive power to calculate the factor that represents the depth of field. The authors found a significant correlation between apparent accommodation and depth of field.

Although higher order aberrations (HOAs) degrade the quality of vision in most circumstances, in some instances they may have a beneficial effect. In the case of presbyopia, specific amounts of spherical aberration may expand the depth of focus without significantly compromising the quality of vision. In a contralateral eye study, we found that residual spherical aberration can enhance the depth of focus and the tolerance to defocus seemed to be higher in eyes implanted with spherical IOLs than in aspheric IOLs. The simulation of positive or negative spherical aberration can have the effect of enhancing the depth of focus with linear shifting of the center of focus by 2.60 diopeters (D) per millimeter of error. This increase in depth of focus can reach up to 2.00 D with 0.6 µm of spherical aberration and is reduced when the aberration is increased to 0.9 µm.

The pupil dynamics under different light circumstances (mesopic and photopic conditions) modifies the effect of the aberration on the depth of focus. The introduction of both positive and negative spherical aberration using adaptive optics technology can significantly shift and expand the patient’s overall depth of focus. Due to the waveform shape, negative spherical aberration seems ideally suited to achieve a desired increase of the depth of focus in a presbyopic patient with a pupil that has a strong response to accommodation. Functional and anatomical limitations may apply when considering the spherical aberration approach. The variability of the individual’s corneal aberrations and the mesopic versus photopic pupil size dynamics may affect clinical outcomes. Centration may be worth consideration because the pupil shifts nasally and superiorly during accommodation.

We recently presented the effects of HOAs on depth of focus with implantation of neutral (aberration-free) and negative spherical aberrations IOLs using ray-tracing aberrometry (iTrace; Tracey Technologies, Houston, TX). Patients with increased corneal HOAs and an aberration-free IOL (EnVista; Bausch & Lomb, Inc., Rochester, NY) had significantly increased depth of focus, suggesting that pseudoaccommodation could be influenced by HOAs, enhancing intermediate and near vision functionality.

**EXPANDING DEPTH OF FOCUS THROUGH OTHER MECHANISMS**

Several technologies can be applied to enhance the range of vision without splitting light. In addition to the spherical aberration described above, small aperture designs and bioanalogic IOLs can enhance the depth of focus without adding a second or third focal point.

**THE PINHOLE EFFECT: SMALL APERTURE DESIGN**

The small aperture design (IC-8; AcuFocus, Inc., Irvine, CA), similar to the KAMRA corneal inlay (Acu-
Focus, Inc.), creates an extended and continuous range of functional vision. The IOL features an embedded opaque annular mask measuring 3.23 mm in total diameter that blocks unfocused paracentral light rays while allowing paraxial light rays through its 1.36-mm central aperture. One advantage to the small aperture effect is the forgiveness to a missed target refraction. At 12 months, 100%, 100%, and 92% of patients achieved 20/32 or better uncorrected distance, intermediate, and near visual acuities, respectively. One hundred percent of eyes maintained 20/40 or better visual acuity over a range of +0.50 to -1.50 D of defocus. Patients’ visual symptoms were rated on the lower end of the severity scale. The IC-8 IOL model may be suitable for post-refractive presbyopes, irregular corneas, and monofocal pseudophakic patients.

**Bioanalogic IOL**

The Wichterle Intraocular Lens-Continuous Focus (WIOl-CF) (Medicem, Czech Republic) has a unique one-piece polyfocal hyperbolic optics with no haptic elements. Produced from a proprietary hydrogel designed to mimic the properties of the natural young crystalline lens (refractive index 1.43, biocompatible hydrogel 42% water); the clear lens enables a continuous range of focus. The refractive power is maximal in the center and continuously decreases without steps to the periphery. Observational studies indicated excellent visual acuity for far and intermediate vision and reasonably good near vision with minimal optical phenomena.

**Echelette Technology**

The echelette design of the Symfony IOL forms a step structure whose modification of height, spacing, and profile of the echelette extends the depth of focus. These design features in combination with achromatic technology and negative spherical aberration correction improve simulated retinal image quality without compromising depth of field or tolerance to decentration. Pedrotti et al. conducted a prospective study comparing bilateral implantation of a monofocal IOL with negative spherical aberration (Tecnis ZCBOO; Abbott Medical Optics) and an EDF IOL (Symfony). The authors reported improved uncorrected intermediate and near visual acuities in the EDF IOL group with no statistically significant differences in contrast sensitivity (CST 1800; Vision Sciences Research Corporation, Lafayette, CA) and optical quality parameters (OQAS; Visiometrics, Cerdanyola del Vallès, Spain). The Concerto Study Group evaluated 411 patients who underwent bilateral implantation of the Symfony IOL, with intended micro-monovision (- 0.50 to - 0.75 D) in one group and intended emmetropia in the second group. They found better spectacle independence in the micro-monovision group. Although more than 90% (368 patients) reported no or mild dysphotopias, a small percent of patients were found to be clinically symptomatic. Therefore, similar to multifocal bifocals and trifocals, patients should be properly counseled about possible photic phenomena.

Overall, patients experience less glare and halos with EDF IOLs; however, improvement at near may be modest. To compensate for the decrease in near vision in patients with EDF IOLs, mini-monovision or mix-and-match strategies with diffractive low-add lenses should be considered. Of note, if the mini-monovision technique is chosen, patients may report decrease in far vision and additional halos from the low myopia in the contralateral eye. Similar to any multifocal IOL, the best visual results with the Symfony IOL depend on patient selection, accurate biometry, astigmatism correction, and IOL centration. Special considerations should be used in patients with corneal HOA aberrations greater than 0.50 µm for a 6-mm pupil size and chord µ (the distance between the pupil center and the patient-fixated coaxially sighted corneal light reflex) exceeding 0.6 mm.

Manifest refraction techniques unique to echelette technology should be used to avoid over-minus endpoints. Similar to young patients, a “push plus” technique should be performed and the examiner should watch for the “refractive plateau.” Autorefractors commonly use infrared light with chromatic aberration correction; thus, we expect myopic results with the echelette’s achromatic technology.

**Conclusion**

Presbyopia-correcting IOLs have become a sought-after option for active patients who desire a range of vision suitable for their everyday activities. The goal of the “elongated focus” design is to address patient expectations and demand for presbyopia correction without compromising visual function.

The EDF category lenses are promising for patients deemed unsuitable for multifocal lenses, such as those who have had previous refractive surgery, suspected glaucoma, and mild dry macular degeneration. Data are lacking for use of the aforementioned lenses in patients with advanced macular degeneration, epiretinal membrane and macular thickening, keratopathy, optic neuropathy, or prisms in their spectacles. In these cases, caution should be exercised because patients may experience unwanted visual symptoms.

The latest EDF technologies open the door to various optical strategies and combinations. For instance, EDF optics may be added to accommodating IOLs to...
provide a synergistic effect for near performance. Furthermore, additional toric EDF platforms may be developed to address astigmatism. Future research will continue toward finding a balance between quality and range of vision.

REFERENCES


