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Extended Depth-of-Field Intraocular Lenses: An Update

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Abstract: Extended depth-of-focus (EDOF) is a new intraocular lens (IOL) technology in the treatment of presbyopia. In contrast to multifocal (MF) IOLs, EDOF lenses create a single elongated focal point, rather than several foci, to enhance depth of focus. In this way, EDOF IOLs aim to reduce photic phenomena, glare, and halos, which have been reported in MF IOLs. A potential disadvantage is a decrease of retinal image quality if the amount of the aberrations is excessively increased. Frequently, EDOF IOLs are combined with MF optical designs; for this reason, EDOF IOLs are commonly a subject of confusion with optical multifocality concepts. The aim of this article is to clarify what an EDOF IOL is and to discuss the recently reported outcomes with these IOLs. We propose naming lenses that have combined optical designs as "hybrid IOLs."

Key Words: extended depth-of-focus, hybrid lenses, intraocular lenses, presbyopia, retinal quality image

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Intraocular lenses (IOLs) are used in both refractive lens exchange and cataract surgery to replace the natural human lens and/or correct refractive errors. Over the recent years, a wide spectrum of multifocal (MF) IOLs has been developed; these IOLs have outweighed traditional monofocal IOLs. With the increase of life expectancy and a change in lifestyle, an increasing number of patients is requesting for spectacle-independent near and intermediate vision for their daily activities, aside from excellent distance vision.[1] Moreover, presbyopia-correcting IOLs are a treatment option for presbyopic patients who are not candidates for laser refractive surgery and do not want to rely on reading glasses.

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Presbyopia-correcting IOLs can be divided into 3 broad categories: MF IOLs (including diffractive or refractive designs), extended depth-of-focus (EDOF) IOLs, and accommodative IOLs (intracapsular or sulcus placed).[2,3]

The aim of this article is to give a brief overview of the contemporary, frequently implanted EDOF IOLs. We decided to focus on the physical aspects of the IOLs and discuss the principal factors that could influence the neuroadaptation. Being a concise overview, many issues can only be touched upon. IOLs that are advertised as EDOF lenses but do not have true EDOF characteristics are discussed below; however, they are not presented in the Table 1.

DEFINITION OF AN EDOF

The EDOF IOL, or extended range of vision IOL, is a new technology in the treatment of presbyopia-correcting lenses. The basic optical principle is to create a single-elongated focal point to enhance the depth-of-focus, on the contrary to monofocal IOLs (in which light is focused on one single point) or MF IOLs (having 2 or 3 discrete points).

This elongated focus is introduced to eliminate the overlapping of near and far images caused by traditional MF IOLs, thus eliminating the halo effect; ideally, these IOLs should enhance intermediate and near visual performance, while minimally affecting distance vision. EDOF IOLs provide a continuous range of focus without a clearly asymmetric IOL power distribution, avoiding the presence of secondary out-of-focus images.[4,5] In this way, EDOF IOLs differ from the MF IOLs which show at each of their foci secondary out-of-focus images corresponding to the rest of the foci, which originate halos and whose characteristics depend on the lens design (especially the magnitude of the addiction) and pupil size.[3] Increasing depth of field might have a tradeoff, which is a decrease visual quality. Particularly, if the aberration magnitude is too large it leads to a reduction in distance image quality, overlapping of the percepted images, with dysphotopsia phenomena.[6] Several optical bench reports have shown that the EDOF lenses provide better optical quality than MF and monofocal lenses.[7–9] Nevertheless, in practice, EDOF lenses provide excellent intermediate vision, but inadequate quality of vision for near distance.[10,11]

The idea of EDOF is not new. Nakazawa and Ohtsuki, in 1984, reported the effect of apparent 2.00 D accommodation in 39 eyes implanted with spherical IOLs.[12] The authors also measured each patient's pupillary diameter, anterior chamber depth, and corneal refractive power to determine the factor that is accountable for the increased depth of field. It was surmised that the correlation between apparent accommodation and depth of field was inversely proportional to the pupillary diameter.[12]

TABLE 1. IOLs Having an EDOF Characteristic

Type	IOL	Material	Design	Optic Size	Overall Size
Pure EDOF IOLs	**Spherical aberration-based EDOF IOLs**				
	SIFI Mini Well Ready	Hydrophilic Acrylic with Hydrophobic Surface	Closed loop	6.0 mm	10.75 mm
	WIOL CF	Hydrophilic Acrylic	Without haptics	8.6–8.9 mm	8.0–8.6 mm
	Tecnis Eyhance ICB00	Hydrophobic Acrylic	C-Loop	6.0 mm	13.0 mm
	EDOF IOLs utilizing the pinhole effect				
	IC-8	Hydrophilic acrylic	C-loop	6.0 mm	12.5 mm
	XtraFocus Pinhole Implant	Hydrophobic acrylic	C-loop (sulcus-placed)	6.0 mm	14.0 mm
Hybrid MF/ EDOF IOLs	**Hybrid MF diffractive/EDOF IOLs**				
	Tecnis Symfony ZXR00	Hydrophobic acrylic	C-Loop	6.0	13.0 mm
	Hybrid MF refractive/EDOF IOLs				
	Lentis Mplus Lentis Mplus X	Hydrophilic acrylic	Plate	6.0 mm	11.0 mm
	Acunex Vario AN6V	Hydrophobic acrylic	C-Loop	6.0 mm	12.5 mm
	Lucidis	Hydrophilic acrylic	Closed loop	6.0 mm	10.8 mm or 12.4 mm
	Hybrid MF refractive-diffractive/EDOF IOLs				
	InFo	Hydrophilic acrylic	Closed loop	6.0 mm	10.8 mm or 12.4 mm
	EDEN	Hydrophobic acrylic	Closed loop	6.0 mm	10.8 mm or 12.4 mm
	Harmonis	Hydrophilic acrylic	Closed loop	6.0 mm	10.8 mm or 12.4 mm
	Tecnis Synergy ZFR00	Hydrophobic acrylic	C-Loop	6.0. mm	13.0 mm

CF indicates continuous focus; EDOF IOLs, extended depth-of-focus intraocular lenses; MF, multifocal; WIOL, Medicem Wichterle Intraocular Lens.

Subsequently, during the past 2 decades, multiple strategies have been used to extend the depth of focus at both the cornea and lens plane.

In June 2014 the first EDOF IOL (Symfony, Johnson and Johnson Vision, Jacksonville, FL) was introduced into the European market, having received the European Economic Area certification mark. Consequently, the Symfony was also the first EDOF-labeled IOL approved in the United States in 2016.[13] Since then, several EDOF-labeled IOLs have been released in the market; these IOLs have been presented in the following paragraphs.

INFLUENCE OF INDUCED ABERRATIONS ON THE QUALITY OF THE RETINAL IMAGE AND THE DEPTH OF FOCUS

Presbyopia correction is the balance of 3 interrelated factors: visual quality, depth of field, and dysphotopsias. The most important optical models employed in EDOF IOLs are presented in the following paragraphs.

Spherical aberration (SA, $Z_{4,0}$) is an aberration associated with focal length difference between central and marginal ray where the light enters in the lens (Fig. 1A). For any given eye, the Zernike coefficients may vary widely, but a mean value of corneal spherical aberration is $+0.31 \pm 0.135\ \mu m$ for a 6.0-mm pupil size.[14] It is possible to neutralize the corneal spherical aberration within a limited degree by choosing a negative spherical aberration IOL. The benefit of an IOL correcting spherical aberrations is to provide a sharper focus of light and therefore a better vision at a particular distance. Although higher-order aberrations (HOAs) degrade the quality of vision in most circumstances, there is evidence that the presence of some HOAs (particularly spherical aberration, coma, and secondary astigmatism) improves depth of focus.[15] This is the principal mechanism than allows to increase the depth-of-focus in pure EDOF IOLs.

Chromatic aberration (CA) is a consequence of focal length difference between the visible spectrum of different colors of light. The human cornea induces CAs, as blue light is diffracted more than red light (Fig. 1B). Several factors affect CAs induced by IOLs. First, the optical material dispersion, which is expressed by the ABBE number, shows how much the refractive index changes with the wavelength of light. The higher the disperision, the smaller the ABBE number. The optical design also has an impact: a refractive optic maintains CA induced by the cornea; with this lens the final ocular CA will increase, with an increasing of the dispersion of the wavelengths. On the contrary, the diffractive IOLs can reverse CA: red blends more than blue. So, a diffractive IOL can minimize the CA in every eye. Achromatization does not bring an extended depth of field improvement but rather an improvement in the contrast sensitivity function.[16] Consequently, a diffractive IOL can minimize CA in every eye, and subsequently lead to an improvement of the contrast sensitivity and the quality of vision.[17]

The pinhole effect is another phenomenon which allows obtaining greater depth of focus. From the equation presented by Campbell over 50 years ago, it can be deduced that with increasing pupil size, the depth of field decreases (and so does the depth of focus).[18] Following this principle, the use of an opaque pinhole mask in a monofocal IOL could enhance the depth of focus. Moreover, the Stiles-Crawford should be taken into accound; it is believed that when an equal intensity of light enters the eye near the center of the pupil, it produces a greater photoreceptor response compared with the light entering the eye near the pupillary edge.[19,20] A review of the advantages of presbyopia correction using the pinhole effect is described elsewhere.

One might conclude that the EDOF effect is achieved just with the increasing of the spherical aberration of the eye or by employing the pinhole effect. To name a lens an EDOF IOL, the optical profile has to be continuous, without a change in transition

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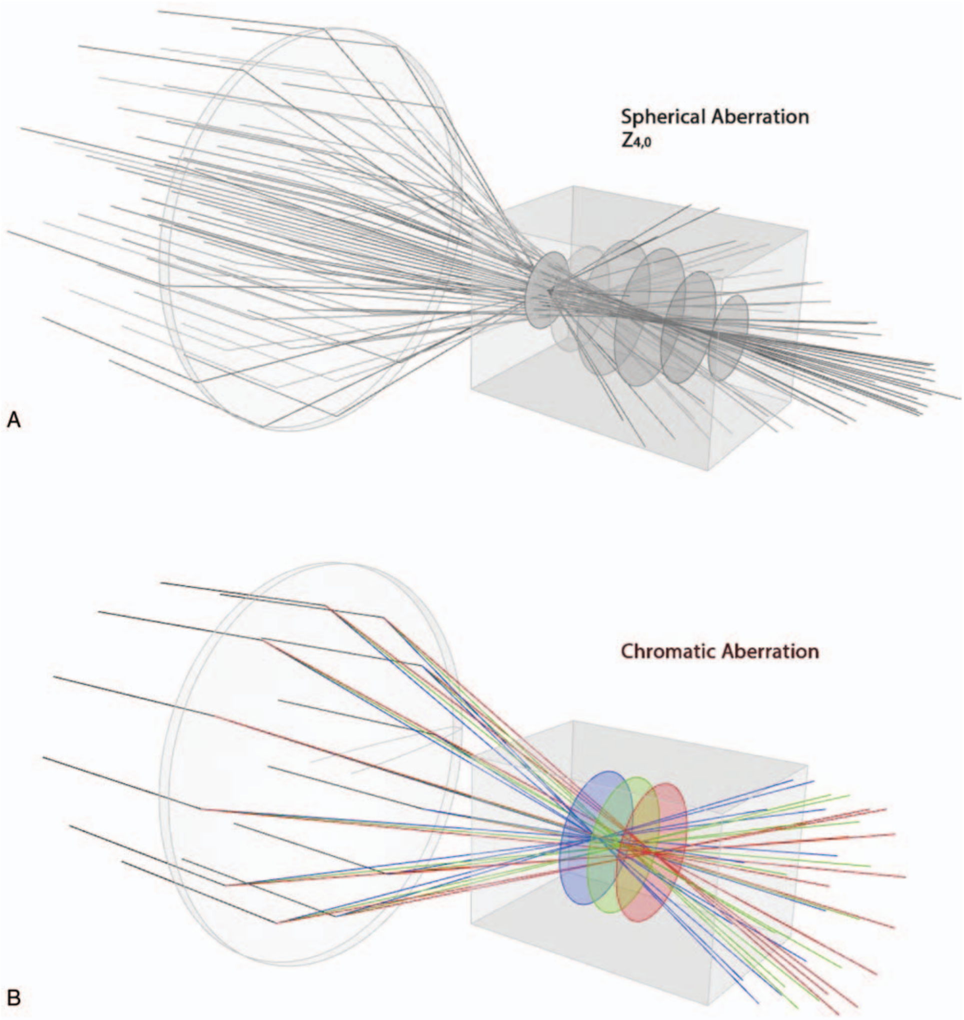

FIGURE 1. Spherical (A) vs chromatic (B) aberrations.

equally refractive or diffractive. All the lenses that employ the CA or have a diffractive diffractive-hybrid profile, or an additional power to increase the near vision are not pure EDOF IOLs.

CLINICAL APPLICATION OF EDOF LENSES

Based on the IOL technologies we believe that 2 groups, pure EDOF IOLs and hybrid MF-EDOF IOLs, should be differentiated. Pure EDOF IOLs employ solely spherical aberration-based optics or the pinhole effect. Hybrid MF-EDOF IOLs could be categorized as diffractive-EDOF IOL, refractive-EDOF IOL, and diffractive-refractive-EDOF IOL.

Pure EDOF IOLs

Spherical Aberration-Based EDOF IOLs

Inducing spherical aberrations in EDOF IOLs means that incoming light waves are extended in a longitudinal plane. The elongated focus eliminates the overlap of near and far images, and theoretically eliminates the halo effect. The tradeoff is a decrease in the quality of the retinal image, which limits their performance as there is a degradation of the visual quality. This is why the near vision capability is usually limited to about 1 D.

Mini Well Ready (SIFI, Catania, Italy) is a one-piece EDOF IOL (Fig. 2A). The optic is purely aberration-based,

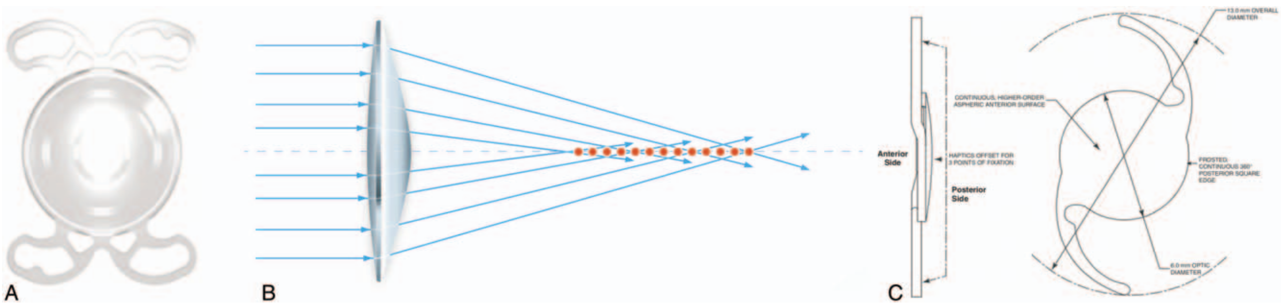

FIGURE 2. Spherical aberration-based EDOF IOLs: (A) Sifi Mini Well Ready, (B) medicem wichterle intraocular lens-continuous focus, (C) Tecnis Eyhance ICB00. EDOF IOLs indicates extended depth-of-focus intraocular lenses.

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and the IOL has a double aspherical optical design. Specifically, the spherical aberrations are induced in certain areas of the optic to increase depth of focus. The optical surface of this IOL is divided into 3 different annular zones: the inner and middle zones have different spherical aberrations with opposite signs, whereas the outer one is a monofocal zone. The primary and secondary spherical aberration, that are insignificant at the pupil center of a real eye in normal conditions, are induced with this IOL in an appropriate amount in some specific areas of the IOL optics, providing an increase of the depth of focus and a control of the level of HOAs. It has an overall diameter of 10.75 mm, an optical surface diameter of 6 mm, and it includes an ultraviolet filter. The lens is made of copolymer, and is also available in a toric version.[5] Theoretically, Mini Well Ready should have a spherical equivalent addition of +3.0 D.[21] Clinical studies reported different results. In a study by Giers et al,[22] the defocus range (defined as visual acuity better than 0.2 LogMAR) reached 4 D; however, still the patients preferred a median intermediate reading distance of 62.8 cm. In another study, increased depth of focus was provided through 2.0 D defocus, the best performance was reported at 1.0 and 1.5 D.[4] Although the lens manifests good optical quality at a large defocus range, the modulation transfer function characteristics are strongly affected by the pupil size.[8,9]

Wichterle Intraocular Lens–Continuous Focus (Medicem, Kamenné Zehrovice, Czech Republic) is categorized as an EDOF lens bioanalogical lenses (Fig. 2B). It enables a continuous range of focus due to a design with a hyperbolic optic. It has a 1-piece polyfocal hyperbolic optic with no haptic elements, and is made from a biocompatible 42% water hydrogel and mimics the properties of a natural crystalline lens with a refractive index 1.43.[23] Although the lack of haptics was supposed to be beneficial, single reports of IOL instability associated with this design have been published[24–26]; the IOL tilt and dislocation had a characteristic pattern and was present despite the absence of trauma.[24] As it is not an accommodative IOL the lens has several zones that create different foci, and the refractive power is maximal in the center and continuously decreases without steps to the periphery. In a clinical study, patients achieved good far and intermediate distance vision, whereas the near vision was relatively good.[27] With that, the amount of HOAs was reasonable.[28]

TECNIS Eyhance ICB00 (Johnson and Johnson Vision, Jacksonville, FL). Although this IOL could be categorized as a monofocal IOL, it offers a smooth and continuous progression of its power from periphery to the center, with no demarcation line (Fig. 2C). It aims to present the distance performance and minimum photic effects of a monofocal (ZCB00) while providing intermediate vision at 66 cm and compensating for spherical aberrations in the cornea. It is a single-piece hydrophobic acrylic IOL wit a 360 degree posterior square edge. The refractive index is 1.47, and clinically it leads to an improvement in intermediate-distance vision when compared to monofocal IOLs. Regarding defocus, measurements indicate that the TECNIS Eyhance IOL has a larger "landing zone" than the TECNIS Monofocal IOL, and provides excellent (20/20) distance vision.[29]

EDOF IOLs Utilizing the Pinhole Effect

IC-8 (AcuFocus Inc, CA) is a 1-piece small aperture extended depth of focus IOL. The optic presents a small aperture aspherical surface, 3.23 mm nondiffractive annular opaque mask with 1.36 mm aperture, which blocks defocused paracentral light rays, and allows entry of paraxial light rays giving an EDOF effect (Fig. 3A). It is a hydrophilic acrylic IOL, and the total diameter is 12.50 mm, with a 6.0-mm optic. It is not pupil-dependent.[30] Clinical studies have shown that the IC-8 provides excellent visual acuity at all distances, both after contralateral and after bilateral implantation.[31–33] The increase in depth-of-focus for the IC-8 is particularly evident in photopic conditions.[33] Moreover, the visual field with the pinhole design shows a small, but clinically insignificant reduction in contrast sensitivity.[34] Another study reported no influence on contrast sensitivity for mesopic conditions with or without glare at all spatial frequencies.[31]

XtraFocus Pinhole Implant (Morcher, Stuttgart, Germany). It is intended for ciliary sulcus implantation as a piggyback lens (Fig. 3B). Its overall diameter is 14 mm with a central pinhole opening of 1.3 mm. The device is made of a black hydrophobic acrylic which blocks visible light but is transparent to infrared light >750 nm, to permit retinal examination through the opaque material with optical coherence tomography and scanning laser ophthalmoscope. Although large clinical studies on the XtraFocus Pinhole Implant are not available, a single

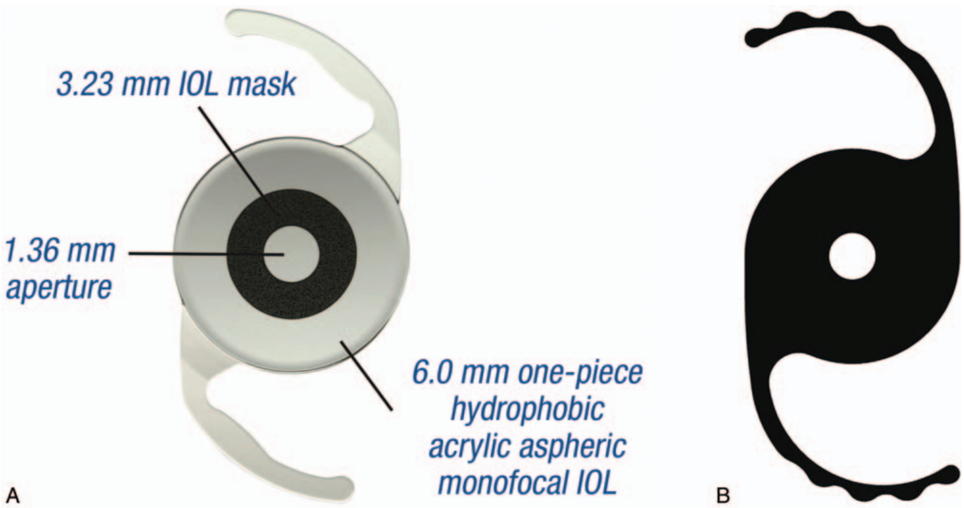

FIGURE 3. EDOF IOLs utilizing the pinhole effect. (A) Acufocus IC-8, (B) XtraFocus Pinhole Implant. EDOF IOLs indicates extended depth-of-focus intraocular lenses.

investigation reported a disadvantage of this design in dim light condition.[35]

Hybrid MF-EDOF IOLs

We propose such a label for IOLs that combine multifocality with low addition power and the EDOF technology.

Hybrid MF Diffractive/EDOF IOLs

New models of diffractive MF IOLs having reached a high standard of clinical performance target the decrease in halos and glare by decreasing the near optical power, substituting it by an EDOF effect.

Tecnis Symfony ZXR00 (Johnson and Johnson Vision, Jacksonville, FL) is a single-piece, hydrophobic acrylic EDOF IOL, foldable lens with a biconvex, anterior aspheric surface, and a posterior achromatic diffractive surface with echelette design (Fig. 4). The asphericity is −0.27m. The performance of this IOL is dependent of the pupil size. Available power spectrum ranges from + 5.0 D to + 34.0 D, with an addition of + 1.75 D at the IOL plane. The lens creates an achromatic diffractive pattern that elongates a single focal point and compensates for the CA of the cornea.[36] Symfony uses 2 complementary enabling technologies: echelette design feature and achromatic technology. The echelette technology is actually used in the Symfony lens and is based on a design that forms a step structure whose modification of height, spacing, and profile of the echelette extends the depth of focus. These designs in combination with achromatic technology and negative spherical aberration correction improve simulated retinal image quality without compromising depth of field or tolerance to decentration.[37] This lens is a low-power MF lens with some EDOF characteristics.[10]

At Lara 29 MP (Carl Zeiss Meditec, Jena, Germany) has a continuous diffractive surface profile from intermediate to distance focal points. It is a hydrophilic acrylic IOL (25% water content) with hydrophobic surface properties. The overall lens diameter is 11 mm with an optical zone of 6 mm.[38] Clinical results confirm excellent visual acuity over a wide range of focus. Binocular visual acuity was better than 0 logMAR (20/20 res. 1.0 decimal) at far and better than 0.1 logMAR (20/25 res. 0.8 decimal) at the intermediate distances of 90 cm and 60 cm.[38] Although the producer claims this is an EDOF IOL,[39] this lens does not have EDOF characteristics.

Hybrid MF Refractive/EDOF IOLs

Lentis Mplus X (Oculentis GmbH, Berlin, Germany) is a rotationally asymmetric refractive MF IOL with a reduced central diameter designed with 2 distinct foci and 2 definite corrective zones for far and for near vision (Fig. 5A). The smooth transition between zones (surface design optimization technology) provides EDOF, increasing near vision effectivity.[40] Additive paraxial asphericity technology is a central modification of the IOL optic, which broadens the 2 foci into far and near focus zones.[41] The sectoral design makes this lens particularly suitable in patients with a pupil diameter >3 mm.[42]

Acunex Vario AN6 V is a foldable 1-piece posterior chamber IOL for extended depth of focus and high-contrast sensitivity with aspherical surface and blue light filter (Fig. 5B). The overall IOL diameter is 12.5 mm, with C-loop haptics, and optical zone of 6 mm. The addition for intermediate vision is + 1.5 D. Both the Acunex and Lentis IOLs share the same basic optical design with a relatively low addition of 1.5 D; however, Acunex is a hydrophobic, whereas Lentis a hydrophilic acrylic lens.

Lucidis (Swiss Advanced Vision, SAV-IOL SA, Neuchâtel, Switzerland) is the new type of refractive/EDOF hybrid IOL involving a central aspheric element surrounded by an outer refractive ring (Fig. 5C). Lucidis is a single-piece foldable multizone refractive/aspheric IOL, with a 360° square edge design and closed loop haptics. The lens has a 6.0-mm optical diameter and a total diameter of either 10.8 mm or 12.4 mm. It is made from hydrophilic acrylic with a 26% water content. The IOL is

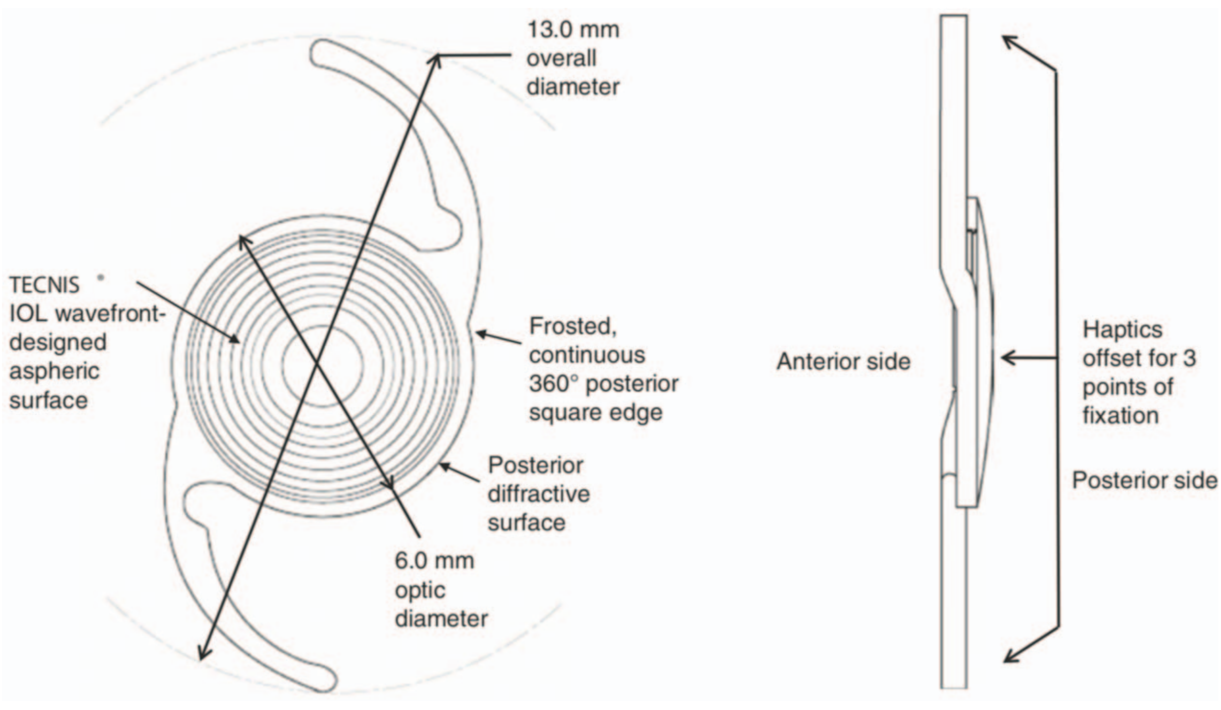

FIGURE 4. Hybrid MF Diffractive/EDOF IOLs: Tecnis Symfony. EDOF IOLs indicates extended depth-of-focus intraocular lenses; MF, multifocal.

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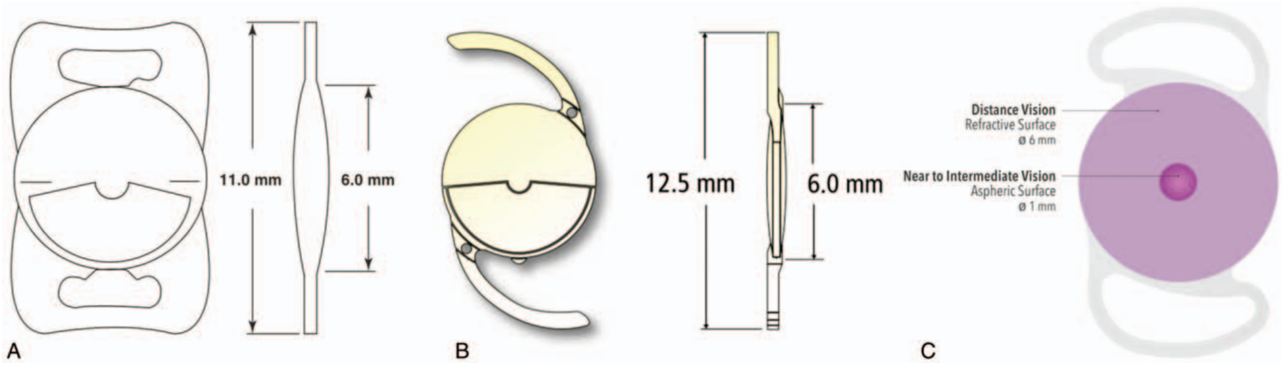

FIGURE 5. Hybrid MF refractive/EDOF IOLs: (A) Lentis Mplus X, (B) Acunex Vario AN6 V, (C) Swiss Advanced Vision Lucidis. EDOF IOLs indicates extended depth-of-focus intraocular lenses; MF, multifocal.

designed for capsular bag implantation and is available in a power range from + 5.0D to + 30.0D in 0.5 D steps with + 3.0 D addiction/EDOF power.[43] Optically, the Lucidis IOL employs both a refractive and an aspheric element. The 1-mm aspheric zone occupies the center of the IOL and is surrounded by a 6-mm refractive ring. According to the manufacturer's documentation, the main benefit of this particular design compared with classical monofocal optics is to provide additional comfort in near and intermediate vision, while still achieving the same optical quality and visual acuity for distance vision. The lens is to be aberration-neutral and minimize the rates of dysphotopsia.[44]

Supraphob Infocus IOL (Appasamy Associates, Chennai, India) is a proprietary newer-generation refractive EDOF IOL, and is really a bifocal refractive lens with an EDOF profile. The IOL is made of acrylic yellow chromophore material and has a small central zone for near vision (3.50 D add), larger mid peripheral zone for intermediate vision, and outer zone for distance vision.[45] This is obviously not real EDOF but rather a bifocal lens which offers a peripheral asphericity to increase the effectivity for near as a support for the optical power of the lens.[10]

Hybrid MF Refractive-Diffractive/EDOF IOLs

InFo–Instant Focus IOL (Swiss Advanced Vision, SAV-IOL SA, Neuchâtel, Switzerland) is an EDOF lens employing a hybrid design. It employs 3 elements: a refractive (6-mm diameter), diffractive element (3.5-mm diameter), and centrally a spheric element (1-mm diameter).[46] The lens has a closed haptic design and is available in 2 sizes: with a total diameter of 10.8 mm and 12.4 mm.

EDEN (Swiss Advanced Vision, SAV-IOL SA, Neuchâtel, Switzerland) is a hybrid MF-EDOF lens, which is foldable1-piece hydrophobic acrylic EDOF IOL (Fig. 6A). The optic is aspheric, refractive-diffractive. The lens is pupil-dependent. The total diameter is 10.8 or 12.4 mm, with an optic size of 6.0 mm.[47]

Harmonis (Swiss Advanced Vision, SAV-IOL SA, Neuchâtel, Switzerland) is a foldable 1-piece hydrophilic acrylic EDOF IOL (Fig. 6B). The optic is aspheric, refractive-diffractive. The lens is pupil-dependent. The total diameter is 10.8 or 12.4 mm, with an optic size of 6.0 mm. The EDOF effect is + 1.0 D to 2.0 D (0.5 D increments).[48]

Synergy: ZFR00 (Johnson and Johnson Vision, Jacksonville, FL) is a bifocal combined with EDOF technology for intermediate vision with potentially better visual continuity than trifocal lenses (Fig. 6C). It features a wavefront-designed aspheric surface and keeps the CAs corrections offered on the Symfony. Its posterior surface is diffractive with 15 rings.[49]

DISCUSSION

Laboratory Versus Clinical Outcomes

The introduction of reduced near add in MF IOLs has paved the way to the development of EDOF IOLs, and they have become a plausible alternative to traditional MF IOLs. Assessment of the quality of vision and optical/refractive performance of EDOF IOLs can be challenging due to the wide array of procedures available for evaluation of these lenses. In some cases, even if the

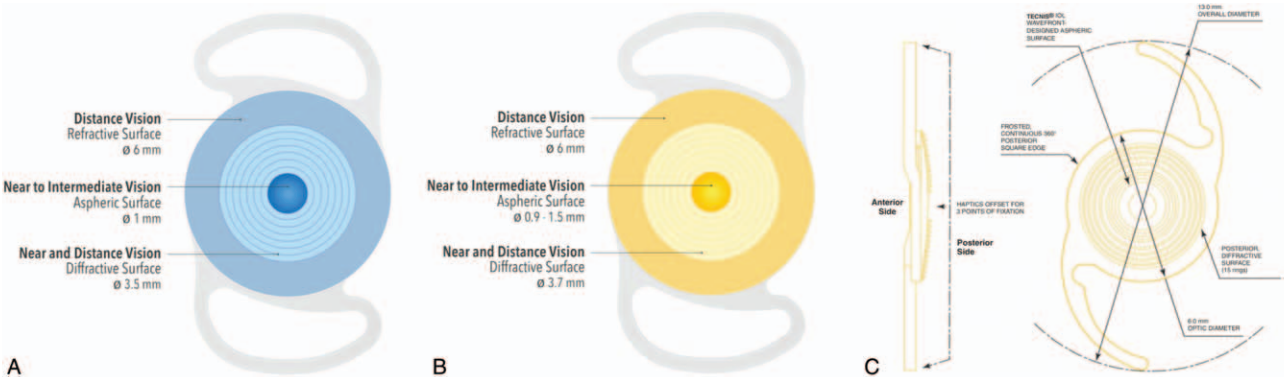

FIGURE 6. Hybrid MF Refractive-Diffractive/EDOF IOLs: (A) Swiss Advanced Vision Eden, (B) Swiss Advanced Vision Harmonis, (C) Tecnis Synergy: ZFR00. EDOF IOLs indicates extended depth-of-focus intraocular lenses; MF, multifocal.

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optical laboratory benchmark study shows that an IOL has supreme optical properties, these results are not always correlated with patient satisfaction and spectacle independence in the subsequent clinical trials. For example, the initial results of the Wichterle Intraocular Lens−Continuous Focus performance were presented in an observational study made by a Czech research group; they indicated excellent visual acuity for far and intermediate vision and reasonably good near vision with minimal optical phenomena.[27] Although the preliminary data were encouraging, recent investigations revealed high rate of poor quality of vision and a consistent pattern of spontaneous dislocation of the lens. The lens was withdrawn from the market and the company ceased commercial activities in October 2018.[28]

For several IOL types, the currently available clinical evidence is limited. In 2017, the American Academy of Ophthalmology Task Force Consensus Statement for EDOF IOLs was published.[50] The report proposed criteria to evaluate clinical performance of EDOF IOLs, and recommended a minimum of 100 patients in the EDOF IOL group (with a control group of similar size). The depth of focus for an EDOF IOLs should be at least 0.5 diopters greater than the depth of focus for a monofocal IOL at logMAR 0.2 (20/32) Nevertheless, none of the currently published studies fulfills all the aforementioned requirements. For further information on visual performance, spectacle independence, and patient satisfaction, we refer the reader to the previously mentioned reviews and references therein.[13]

EDOF Versus MF IOLs

Breyer et al noted that with EDOF IOLs distance and intermediate VA are good; however, near vision still falls short for most of the EDOF lenses.[17] Although some studies reported satisfactory quality of near vision with EDOF IOLs, this issue is controversial.[51] One of the ways to compensate the insufficiency in near visual acuity in patients with EDOF lenses is mini-monovision, or mix-and-match strategies with diffractive low-add lenses which should be considered; nevertheless, using the mini-monovision may cause decrease in far vision and additional halos from the low myopia in the contralateral eye.[36] These studies indicate that mix and match and blended vision with MF IOLs or EDOF IOLs are promising treatment options for cataract or refractive surgery in patients who strongly desire increased spectacle independence; blended vision with EDOF IOLs particularly represents a viable treatment alternative to trifocal IOL implantation.

We believe EDOF lenses should be used as monofocal lenses with a minor improvement for near vision; they can be expected to provide bad quality of near vision, whereas intermediate vision can be adequate.[10] For MF hybrid IOLs, one can reduce the quality of near vision but keeping intermediate vision the same quality of retinal image but at the same time you decrease the halos and glare. So, this is probably for conservative indications. If a patient requires good near vision with an IOL, we believe that he should receive an MF lens (a refractive and diffractive model) making the choice depending on the patient profile and preferences. It is not an easy task to make the choice of lenses and this is why objective information based on aberrometer internal component information would be required. It would also be important to develop a standardized objective means of measuring and reporting visual and refractive outcomes with these lenses, as a guide for clinicians in the future.

Neuroadaptation is a major concern in MF or EDOF IOLs; this process is time-consuming and dependent on individual factors (of which some are unknown).[52] Pure EDOF lenses with a relevant amount of aberrations to improve near vision may be difficult to tolerate by the patient; although the brain is adapted to a certain amount of aberrations over time, a sudden increase in aberrations may not be accepted. Regarding photic phenomena the evidence is scarce; however, some studies reported a lower intensity of photic phenomena in EDOF IOLs when compared with MF IOLs.[5] Particularly, Savini et al[5] reported smaller mean size and lower mean intensity of photic phenomena in Mini Well than in the ReSTOR SV25T. In the Concerto patients reported minimal photic phenomena with the Symfony IOL; 4 to 6 months after surgery 87.0% to 97.6% of individuals had no/mild intensity of halos, glare, or starburst perception.[36]

Confusion in Terminology

The pure EDOF lens is a lens that has spherical aberration increased to elongate the focus but has no multifocality. In doing that, certain amounts of ocular aberrations are increased on purpose to create the minimal blur necessary to see different distances, even though with a “blur.”[10] The cost of this might be degraded quality of vision. We believe that an IOL should be named an EDOF lens when it does not have either refractive or diffractive added multifocality.[10] Importantly, the EDOF technology cannot provide more than a 1 D range of focus.

For example, the Symphony, Synchrony, At Lara tri are hybrid IOLs, which combine an EDOF with multifocality. Those lenses that have attempted to provide more are either out of the market or the company has closed, or have very bad results and the reason is that the quality of the retinal image for the first time we are able to see the retina image quality with the pyramidal aberrometry, and the results are very different.

Multifocality and EDOF characteristics are not exclusive of each other. A bifocal IOL may exhibit EDOF characteristics, likewise with an aspheric monofocal IOL or even a diffractive or refractive trifocal IOL. Range of vision is partly limited compared with modern MIOLs (trifocal)—limitation for near. Otherwise EDOF IOLs could potentially induce less dysphotopic phenomena compared with MF IOLs.

Future research will continue toward finding a balance between quality of vision, EDOF, and dysphotopsias.[53] The question still remains, however, as to how we can maximize postoperative vision at all distances with these lenses? Could IOL design be improved, or should more hybrid IOLs be introduced into the market? Or maybe we should consider blended implantation? Counseling and advice are needed to ensure satisfactory outcomes—for both the patient and the surgeon.

CONCLUSIONS

There is a wide range of IOLs available in the market; a careful and complete examination of the patient and the IOL selection which is based on his lifestyle and visual needs would be recommended. There is confusion in the terminology; some of the so-called EDOF lenses available today are really MF lenses with low near add power, in which part of the rest of the power has been withdrawn to avoid the overlapping of images and the consequent halos and glare, by a certain standard of focus caused by the induction of spherical aberration to a certain level. We propose an

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alternative terminology and naming lenses that have combined optical designs as “hybrid IOLs.”

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