



Multifocal and Extended Depth-of-Focus Intraocular Lenses in 2020

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Ophthalmic surgeons have been overwhelmed by the influx of multifocal intraocular lens (IOL) options in recent years, with close to 100 IOLs on the market in 2020. This practical and technical update on a representative group of established as well as newly launched multifocal IOLs on the market focuses on multifocal IOLs, including extended depth-of-focus lenses. We also describe the optical basis of lens platforms used and thorough pre-operative planning to aid decision making. This allows the surgeon the knowledge base to deliver the required relative customized spectacle independence with the least photic phenomenon and loss of contrast possible while achieving high individual patient satisfaction. Data of reviewed IOLs displayed in tabular format include mean monocular uncorrected distance, intermediate, and near visual acuities (logarithm of the minimum angle of resolution), with standard deviations and ranges where available. The range of vision targeted, pupil dependence, toric availability, as well as type of optical platform, are provided as a practical guide to demystify existing terminology on the market that may create interest around a seemingly new design that is actually not novel at all. Halos and glare experienced, levels of patient satisfaction, and spectacle independence achieved also are summarized. A wide range of multifocal IOLs options are available on the market to surgeons. Comprehensive patient selection and examination, combined with knowledge of the most recent options and adequate patient counseling, including neuroadaptation, can avoid dissatisfaction. Many recently available IOLs are awaiting formal results, but the methods by which we label and compare these types of IOLs must also be standardized. *Ophthalmology* 2020;■:1–22 © 2020 by the American Academy of Ophthalmology



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Intraocular lens (IOL) technology for refractive lens exchange, presbyopia, and cataracts has evolved dramatically in the last 30 years, with high patient expectations not only for distance vision but also for near as well as intermediate vision.^{1–5} Various strategies have been used to compensate for presbyopia, which occurs naturally after cataract surgery. Because monofocal lenses allow only for best uncorrected visual acuity at a fixed distance, minivision has been offered commonly, in which the dominant eye is targeted for distance vision and the nondominant eye is aimed for intermediate or near vision.^{6–9} Unfortunately, this approach has inherent limitations, including loss of stereopsis.

The first multifocal lens was implanted by Keates et al¹⁰ in 1986. Although earlier multifocal lens designs included an inherent optical compromise, such as significantly reduced contrast sensitivity and severe photic phenomenon, performance is improving at a fast pace, and a larger percentage of patients are achieving high satisfaction and spectacle independence.⁴ Ideally, surgeons would like to implant an IOL that has the possibility to change its power or position as a response to the accommodative mechanism and contraction of the ciliary muscle. Although so far 12 accommodative IOLs have been introduced that theoretically can change their power when the ciliary muscle is activated by the accommodation reflex, their effectiveness and safety have

yet to be proven clinically in practice.^{3,11} Presbyopia-correcting lenses, relying on the principle of simultaneous vision, have been introduced to provide increased or total spectacle independence and can be divided into 2 broad categories: multifocal IOLs and extended depth-of-focus (EDoF) IOLs. The American Academy of Ophthalmology task force has issued a consensus statement that EDoF IOLs should have an extended far focus area that reaches the intermediate distance, providing excellent distance and intermediate vision.¹² In cases of bilateral multifocal IOL implantation, it is possible to combine different types of IOLs to improve binocular vision and increase the range of distances, also known as mix-and-match or blended vision.¹³ Currently, we identified at least 70 multifocal and EDoF IOLs on the international market, with [Figure 1](#) highlighting some established as well as newer-generation IOLs representing the different optical platforms available. Because of the rate of expansion of the market, it is not possible to include every single lens, but we are able to cover the most popular as well as upcoming lenses.

We present the most comprehensive and user-friendly update of multifocal IOLs, with a focus on the newest multifocal and EDoF IOLs, the latter also known as extended range-of-vision IOLs, including a mention of those just being released onto the market.^{14–16} A shift is currently taking place in the market toward developing EDoF IOLs, mainly to differentiate themselves from

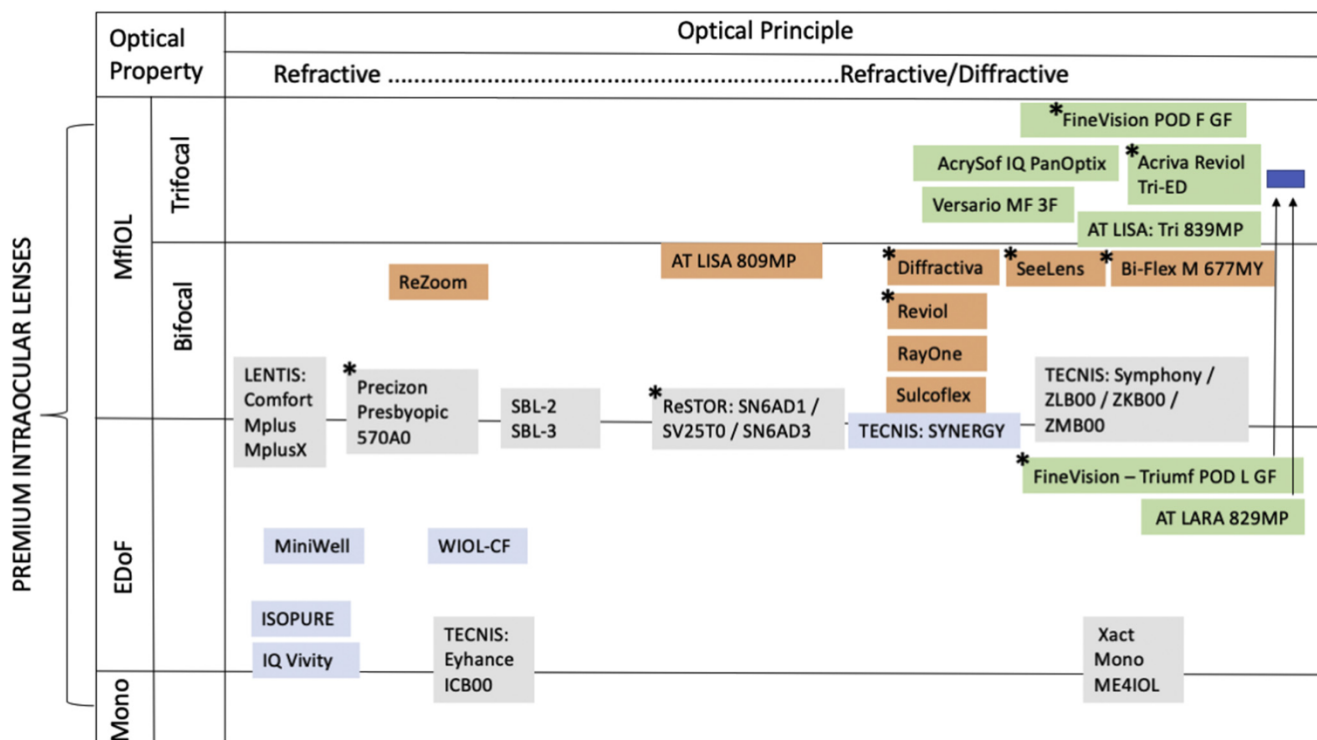


Figure 1. Diagram showing optical principles used to achieve multifocality in intraocular lenses (IOLs). On the left are the different optical properties, and along the top are the optical principles. FineVision Triumpf and Zeiss AT LARA are the only trifocal extended depth-of-focus (EDoF) IOLs on the market and straddle the table between EDoF and trifocal. Apodized lenses are marked with an asterisk. We have not included the IC-8 by Acufocus or the Crystalens by Bausch & Lomb. Although these are part of the multifocal IOL (MfIOL) market, they are not our focus in this review of the MfIOL and EDoF range.¹⁸ Mono = monofocal.

multifocal IOLs, which seem to have developed a stigma for dysphotopsia and discrete, rather than continuous and smooth focus. Special attention is given to exploring the similarities and differences between the design concepts used for these IOLs, as well as clinical thought processes and examples to aid decision making. This article also expands on the study of the optical properties that govern multifocality and the control of chromatic aberrations in relation to this, allowing a novice in this field to learn the basics and the practical applications of this knowledge simultaneously.^{17,18}

General Principles: Simultaneous Vision

In an emmetropic eye, monofocal IOLs will form a sharp image at the retinal plane, providing a detailed and high-contrast image for distance but a blurred and low-contrast image for the near and intermediate vision. Simultaneous vision corrections superimpose a focused image as well as a defocused image on the retina. This is because multiple foci are corrected, with some focused for far and others for near. Therefore, the success of simultaneous vision relies on the ability of the human brain to select, among the superimposed images, a primary in-focus image, while suppressing the blurred out-of-focus image, also known as neuroadaptation.^{19,20} Multifocal and EDoF IOLs have 2 or more distinct powers within their aperture, whereby

both in-focus and out-of-focus images are presented at the retina simultaneously. The brain must interpret the sharp component, providing suitable vision for the distance of interest, while filtering out the blurred component. This ability to suppress varies among individuals,²¹ where failure to do so can generate large amounts of blur and can reduce the contrast sensitivity.

Optical Design and Properties of Multifocal and Extended Depth-of-Focus Intraocular Lenses

Two optical phenomena can be exploited to create multifocal optics: refraction and diffraction.

Refractive Intraocular Lenses

Pure refractive lenses can be zonal, aspheric, or both. **Zonal Refractive Lenses.** Zonal refractive lenses have distinct regions or zones that refract light differently, with refraction solely determining the way the light rays bend in these large zones. The optical power is dependent on the local surface curvature, with regions of differing curvatures achieving different powers within the lens. To avoid stray light effects, the transition between these regions is blended. The design of the blend zone can be achieved by introducing regions of intermediate power, where multiple annular

Table 1. Frequently Used and Recently Launched Multifocal Intraocular Lenses, with a Focus on Trifocal and Extended Depth-of-Focus Lenses, with Published or Relevant Presented Data

Row No.	Class and Expected Range (D)	Intraocular Lens Family or Model	Material	Study Author(s) and Year (No. of Eyes)	Visual Acuity, Mean (Standard Deviation, Range)			Halo/Glare (% If Available)	Satisfied	Spectacle Free (%)
					Uncorrected Distance	Uncorrected Intermediate	Uncorrected Near			
A1	EDoF monofocal refractive, +1.53 defocus range	Vivity DFT015, Alcon (T) Pupil independent	1-piece, non-diffractive, wavefront shaping, based on SN60WF monofocal lens	Poyales, 2019, ¹ ESCRS (156), international Mearza et al, 2019 ² ESCRS (28) UK subset	Bi 0.013 Bi -0.003	Bi 0.06 Bi 0.094	Bi 0.232 Bi 0.275	25/25 low/low Low/low	—	—
A2	EDoF monofocal refractive +1.00 defocus range	Isopure 1.2.3 GF, Physiol Pupil independent	1-piece, aspheric, hydrophobic Acrylic, isofocal technology	Bilbao-Calabuig et al, 2019, ³ ESCRS	—	—	—	—	—	—
B1	EDoF monofocal refractive +1.3 defocus range	EyHance ICB00, J & J Pupil dependent	1-piece, without rings, hydrophobic, acrylic, biconvex, anterior aspheric surface	Batisic, 2019, ⁴ ESCRS (46) Good preliminary results	Decimals 0.91 (0.13) Equivalent to 0 (0.1)	Good preliminary results	Good preliminary results	Low	High	High
B2	EDoF bifocal refractive +1.5 N	LENTIS Comfort MF15, oculentis (T) Pupil independent	1-piece, asymmetrical, hydrophilic, acrylic, biconvex, aspheric, posterior hydrosmart copolymer	Vounourypidis et al, 2017 ⁵ (44) Alió et al, 2011 ⁶ (21)	0.07 (0.1) 0.21 (0.24)	0.21 (0.15) 0.21 (0.13)	0.53 (0.15) 0.24 (0.14)	Low <10 Low	High High	— —
B3	EDoF bifocal refractive +3.5 N	ReZoom, JSJ previously Abbott Pupil dependent	3-piece, acrylic, biconvex, anterior refractive zonal progressive surface	PePOSE et al, 2007, ⁷ (28) Chiam et al, 2007, ⁸ (50) Mesci et al, 2010 ⁹ , (20) Gil et al, 2012, ¹⁰ (22)	0.07 Bi 0.00 0.06 Bi 0.04	0.15 Bi 0.23 0.36 Bi 0.18	0.25 Bi 0.23 0.07 Bi 0.26	Mod 28/14 low 35/18 low 18.2/18.2 low	High Moderate 70 94.7	— 70 90 100 D/N 36.4 N
B4	EDoF bifocal refractive +2.5 N	MiniWell ready (T), SIFI Medtech Pupil dependent	1-piece, aberration-based, biconvex, double aspheric copolymer, hydrophilic	Giers et al, 2019 ¹¹ (28) Savini et al, 2018, ¹² (20) Taylor, 2019, ¹³ ESCRS Gatnel, 2019, ¹⁴ ESCRS	0.13 (-0.08 to 0.42) 0.04 (0.06)	-0.05 (-0.18 to 0.58) 0.08 (0.09)	0.14 (-0.1 to 0.64) 0.33 (0.15)	Low 10/5 low	High —	High High
C1	EDoF trifocal diffractive refractive +3.5 N +1.75 I	Triumf POD L / GF, Physiol Pupil dependent	1-piece, LCA-free, apodized, hydrophobic, acrylic		Promising optical bench results					

(Continued)

Table 1. (Continued.)

Row No.	Class and Expected Range (D)	Intraocular Lens Family or Model	Material	Study Author(s) and Year (No. of Eyes)	Visual Acuity, Mean (Standard Deviation, Range)			Halo/Glare (% If Available)	Satisfied	Spectacle Free (%)
					Uncorrected Distance	Uncorrected Intermediate	Uncorrected Near			
C2	EDoF trifocal diffractive +1.9 defocus range	AT LARA 829MP, Zeiss (T) 929M/MP Pupil dependent	1-piece, aspheric, acrylic, hydrophilic/phobic surface, echelette design	Kretz et al, 2018 ¹⁵ (22)	0.04 (0.11)	Corr 0.13 (0.11)	Corr 0.4 (0.16)	Low	High	—
C3	ERoV bifocal diffractive +1.5 defocus range	Tecnis Symfony ZXR00, J & J (T) Pupil dependent	1-piece, biconvex, anterior aspheric, posterior achromatic, acrylic, hydrophobic, echelette design	Cochener and Concerto Study Group 2016 ⁶ (822) Black 2018 ¹⁷ (30) Hogarty 2018 et al, ¹⁸ (86) Pedrotti 2016 et al, ¹⁹ (50) Pandit, 2018 ²⁰ (100) Cochener 2018 et al, ²¹ (20) Canovas, 2019, ²² ESCRS	Bi 0.03 (0.1, -0.3 to 0.48) -0.04 (0.05) 0.04 (0.11) 0.08 (0.12) 0.02 (0.09) 0.1 (0.2)	Bi 0.12 (0.16, -0.3 to 1) 0.01 (0.08) 0.18 (0.11) 0.24 (0.11) — 0.2 (0.18)	Bi 0.19(0.17, -0.1 to 0.8) 0.30 (0.14) 0.28 (0.12) 0.27 (0.11) 0.12 (0.09) 0.3 (0.17)	Low Low Low Low Low Low	High High High High High High	High High High High High High >90%
C4	EDoF bifocal diffractive +3.0 defocus range	Synergy ZFR00, J & J Pupil independent	1-piece, technology combination of bifocal + Tecnis Symfony	Promising simulated bench tests	0.09 0.13	Bi 0.17 Bi 0.16	0.3 —	Low Low	High High	High —
C5	EDoF monofocal diffractive +1.5 defocus range	Xact ME4 monofocal EDof, Santen Pupil independent	1-piece, hydrophobic, acrylic, biconvex	Packer, 2019 ²³ (45), ESCRS, 2019 Baur, 2019 ^{23,24} (29), ESCRS 2019	0.00 (0.05)	0.06 (0.13)	0.00 (0.05)	Low	High	91.6
C6	EDoF bifocal diffractive refractive +3.0 defocus range +3.5 N	Diffractiva Diff-Aa, HumanOptics AG (T) Pupil dependent	1-piece, hydrophilic, glistening free, acrylic diffractive - central, refractive - peripheral, anterior -aspheric, apodized	Dexl et al, 2014 ²⁵ (48)	0.00 (0.05)	0.06 (0.13)	0.00 (0.05)	Low	High	—
C7	Bifocal refractive sectorial +2.75 N	Precision presbyopic 570 AO, Ophtec BV Pupil dependent	1-piece, hybrid, hydrophilic/hydrophobic	Royo et al, 2020 ²⁶ (62)	0.03 (0.04)	0.19 (0.06)	0.04 (0.05)	9.7/6.5 low/low	High	—
D1	Trifocal diffractive +3.5 N +1.5 I	Acryva Reviol Tri-ED611, VSY Biotech (T) Pupil independent	1-piece, active semi-apodized, sinusoidal hydrophobic	Torun Acar et al, 2016 ²⁷ (80)	-0.04 (0.08)	0.08 (0.11)	0.15 (0.12)	Low	High	High

Table 1. (Continued.)

Row No.	Class and Expected Range (D)	Intraocular Lens Family or Model	Material	Study Author(s) and Year (No. of Eyes)	Visual Acuity, Mean (Standard Deviation, Range)			Halo/Glare (% If Available)	Satisfied	Spectacle Free (%)
					Uncorrected Distance	Uncorrected Intermediate	Uncorrected Near			
D2	Trifocal diffractive +3.33 N +1.66 I	AT LISA Tri 839MP, Zeiss (T) Pupil independent	1-piece, aspheric, acrylic, hydrophilic (hydrophobic surface)	Bilbao-Calabuig et al, 2017 ²⁸ (4282) Brito et al, 2015 ²⁹ (33) Tarib et al, 2019 ³⁰ (42) Kretz et al, 2016 ³¹ (100) Mendicure 2016 et al ³² (208) Marques and Ferreira, 2015 ³³ (15)	0.04(0.08, -0.15 to 0.70) 0.022 (0.037, 0 -0.15) 0.13 (0.15) 0.06 (-0.1 to 0.3) Bi 0.10 (0.15) 0.08 (0.12)	0 (0.17, -0.3 to 0.6) — 0.25 (0.19) 0.09 (-0.10 to 0.30) Bi 0.10 (0.15) 0.14 (0.09)	0.07 (0.10, 0 -0.76) 0.123 (0.054, 0 -0.2) 0.25 (0.14) 0.06 (-0.1 -0.3) Bi 0.15 (0.14) 0.22 (0.07)	Low Mono 47 Bi 29 Moderate Low 7.88 low Low	98 — High High 90 High	98 — 76.19 D/I 75 N High >90 100
D3	Trifocal diffractive +3.5 N +1.75 I	FineVision Micro F, Physiol Pupil dependent (T)	1-piece, hydrophilic, acrylic, biconvex anterior, aspheric posterior	Cochener et al, 2018 ²¹ (20) Oliveira et al, 2018 ³⁴ (24) Bilbao-Calabuig et al, 2017 ²⁸ (5802) Cochener, 2016 ³⁵ (30) Cochener et al, 2014 ^{36,37} (198) Sheppard et al, 2013 ³⁸ (30)	0.1 (0.21) 0.19 (0.15, 0.00 -0.59) 0.06 (0.08, -0.10 to 0.82) 0.08 (0.08) 0.01 (0.06) 0.19 (0.09)	0.25 (0.13) 0.15(0.09, -0.10 to 0.4) -0.01(0.15, -0.3 to 0.7) — 0.08 (0.01) High satisfaction	0.2 (0.2) 0.17 (0.13, 0.0 -0.4) 0.08(0.10, 0.00 -1.0) 0.01 (0.01) 0.00 (0.04) High satisfaction	<1 low 8.3 (5 yrs) low Low 92/58 49/31 (<1 yr) 0	90 91.7 96.82 93 High High High	90 — 98 D/I 92 N — 96 D/I 80 N —
D4	Trifocal diffractive	Pod F / GF, Physiol (T) Pupil dependent	1-piece, hydrophilic, acrylic, biconvex anterior, aspheric posterior, glistening free	Poyales 2019 et al, ³⁹ (26) Nagy et al, 2019 ⁴⁰ (25) Ferreira and Ribeiro, 2019 ⁴¹ (20) Ferreira and Ribeiro 2019, ⁴¹ (20) Khan and Muhtaseb 2011, ⁴² (5), (Sulcus) Venter et al, 2014 ⁴³ (80) (Sulcus) Antunes et al, 2014, ⁴⁴ (25) (Sulcus)	0.00 (0.01) 0.00 (0.07, -0.2 to 0.1) 0.04 (0.08) 0.09 (0.11)	0.16 (0.04) 0.04 (0.09, -0.10 to 0.2) 0.05 (0.12)	0.11 (0.12) 0.06(0.08, -0.10 to 0.2) 0.05 (0.12)	— — 33/47 low	High High High	— 100 High
D5	Trifocal diffractive RayOne +3.5 N +1.75 I	RayOne trifocal RA0603F, Rayner (T) Sulcoflex trifocal IOL703F sulcus version Relatively pupil independent	1-piece, hydrophilic, acrylic	Ferreira and Ribeiro 2019, ⁴¹ (20) Khan and Muhtaseb 2011, ⁴² (5), (Sulcus) Venter et al, 2014 ⁴³ (80) (Sulcus) Antunes et al, 2014, ⁴⁴ (25) (Sulcus)	0.03 (0.11) 0.1 0.01 (0.1, -0.1 to 0.3) 0.08 (0.05, 0 -0.17)	0.06 (0.10) — —	0.04 (0.13) 0.4 0.19 (0.15, -0.1 to 0.5) 0.22	60/60 moderate — — 45/36 moderate	High High — High	High — — —
D6	Trifocal diffractive +3.00 N +1.50 I	Versario MF 3F, Valeant Med Pupil dependent	1-piece, hydrophilic with hydrophobic surface, aspheric	Fernandez et al, 2019 ⁴⁵ (30)	0.02 (0.11)	0.19 (0.11)	0.24 (0.14)	Moderate	High 96.3	—

(Continued)

Table 1. (Continued.)

Row No.	Class and Expected Range (D)	Intraocular Lens Family or Model	Material	Study Author(s) and Year (No. of Eyes)	Visual Acuity, Mean (Standard Deviation, Range)			Halo/Glare (% If Available)	Satisfied	Spectacle Free (%)
					Uncorrected Distance	Uncorrected Intermediate	Uncorrected Near			
D7	Trifocal refractive-diffractive +3.25 N +2.17 I	AcrySof IQ Panoptix, Alcon (T) Pupil independent up to 4.5 mm	1-piece, aspheric, diffractive/refractive outer zone, hydrophobic, acrylic	Monaco et al, 2017 ⁴⁶ (40) Bohm et al, 2018 ⁴⁷ , (20) Alió et al, 2018 ⁴⁸ (52) Cochener et al, 2018 ²¹ (20)	0.00 (0.04) 0.04 (0.127) 0.07 (0.1) 0.1 (0.16)	0.23 (0.07) 0.08 (0.115) 0.12 (0.13) 0.3 (0.12)	0.02 (0.06) 0.06 (0.111) 0.16 (0.09) 0.2 (0.11)	15 low Low Moderate Low	High High Moderate/high High	90 D/100 90 N 95 high High
E1	Bifocal refractive-diffractive SN6AD3 +4.00 (N) SN60D1 +3.00 (N) SV25T0 +2.5 (N-I)	ReSTOR SN6AD3 SN60D1-3 (T) SV25T0 (T) Alcon Pupil dependent	1-piece, bifocal, hydrophobic, acrylic, apodized, varying adds, SN60D3 spherical, SN6AD3 aspheric	Alfonso et al, 2007 ⁴⁹ (335) SN60D3 Alfonso et al, 2010 ⁵⁰ (23) SN60D3 Wang et al, 2012 ⁵¹ (24) SN6AD3	0.122 (0.038) 0.02 0.18 (0.12)	Bi 0.356 (0.030) 0.02 0.24 (0.09)	0.057 (0.010) 0.95 (0.07) 0.10 (0.07)	Moderate/low — 33/17 moderate/low	High 96.7 High High	— 96 I, 100 N 75
E2	Bifocal refractive-diffractive +3.00 N I (>0.3 logMAR)	Seelens, Hanita Pupil dependent	1-piece, aspheric, apodized, diffractive, hydrophilic, acrylic, copolymer	Alió et al, 2015 ⁵² (20) van der Linden et al, 2013 ⁵³ (48)	0.22 (0.20, 0.00 -0.93) 0.02 (0, 0.007)	0.27 (0.15, 0.1 -0.6) —	0.24 (0.15, 0 -0.6) 0.09 (0.12)	Low 12 low	High High 96	High High
E3	Bifocal diffractive ZKB00, +2.75 N ZLB00, +3.25 N ZMB00, +4.00 N	Tecnis ZKB00/ ZMB00 (T)/ZLB00, J & J Pupil independent	1-piece, hydrophobic, acrylic, biconvex, aspheric anterior, diffractive posterior	Kim et al, 2015 ⁵⁴ (21), ZKB00 ZKB00 (23), ZLB00 ZMB00 (21) Cochener, 2016 ⁵⁵ (24) Kretz et al, 2015 ⁵⁵ (143) ZKB00	0.07 (0.056) 0.045 (0.042) 0.067 (0.068) 0.11 (0.09) 0.12 (0.18)	0.15 (0.067) 0.14 (0.074) 0.18 (0.083) Bi 0.07(0.05) 0.21 (0.18)	0.17 (0.07) 0.14 (0.075) 0.15 (0.075) 0.02 (0.02) 0.13 (0.28)	39.1/43.4 33.3/47.6 42.9/52.4 67/50 33.9/21.4	High High High 92 high High	87 85.7 76.2 High 84.7
E4	Bifocal diffractive +3.5 N	Bi-Flex M 677MY, Medicontur Pupil independent	Progressive, apodized, diffractive, acrylic	Garcia-Bella et al, ⁵⁶ (50)	0.03 (0.09)	Corr DCIVA 0.2 (0.07)	Corr DCNVA 0.11 (0.08)	Moderate 21% (Likert 3>)	—	—
E5	Bifocal refractive +3.00 N	M-Flex 630F, Rayner (T) Pupil dependent	1-piece, aspheric, hydrophilic, acrylic	Prieto and Bautista 2010 ⁵⁷ (32) Aslam et al, 2009 ⁵⁸ (20)	0.09 (0.09, 0.0 -0.3) 0.18 (0.2)	0.15 (0.05, 0.1 -0.3) —	0.28 (0.11, 0.1 -0.4) 0.4	Low Low	High —	90 Bi D 70 N —
E6	Bifocal refractive +2.00 N	M-plus MF20 Oculentis (T) Pupil independent	1-piece, acrylic, biconvex, aspheric posterior, hydrosmart, acrylate, copolymer	Son et al, 2019 ⁵⁹ (13) (IC-8 in contralateral eye) McNeely et al, 2016 ⁶⁰ (120)	0.01(0.13, -0.26 to 0.26) Bi-0.07 (0.07, 0.2 -0.24)	Bi 0.00 (0.10) 0.38 (0.12, 0.2 -0.7)	Bi 0.11 (0.08) 0.12 (0.11, 0 -0.4)	Low Low	High High	High 93 high

Table 1. (Continued.)

Row No.	Class and Expected Range (D)	Intraocular Lens Family or Model	Material	Study Author(s) and Year (No. of Eyes)	Visual Acuity, Mean (Standard Deviation, Range)				Halo/Glare (% If Available)		Spectacle Free (%)
					Uncorrected Distance	Uncorrected Intermediate	Uncorrected Near	Uncorrected Distance	Uncorrected Intermediate	Uncorrected Near	
E7	Bifocal refractive +3.00 N	M-plus MF30, Oculentis (T) + new M-plus X Pupil independent	1-piece, acrylic, hydrophilic	Berrow 2014 et al, ⁶¹ (34) (Mplus X) Alió et al, 2011 ⁶ (21) (MF30) McNeely et al, 2016 ⁶⁰ (120) (MF30) McNeely et al, 2017 ⁶² (90) (SBL3)	0.10 (0.12) 0.14 (0.11, 0-0.3) -0.08 (0.08, -0.22 to 0.10)	-0.04 (0.14) 0.2 (0.13, 0 -0.52) 0.36 (0.07, 0.2 -0.5)	0.18 (0.16) 0.21 (0.10, 0 -0.3) 0.11(0.11, -0.1 to 0.4)	Low Low Low	High High High	— — 90 high	
E8	Bifocal refractive +3.00 N	SBL-2/3, Lenstec Inc. Pupil dependent	1-piece, acrylic, hydrophilic	McNeely et al, 2017 ⁶² (90) (SBL3)	-0.01 (0.10)	0.4 (0.11)	0.14 (0.12)	Low	High	High 93.3	

Bi = only binocular results available; Corr = only corrected acuities available; D = diopter; DCIVA = distance corrected intermediate visual acuity; DCNVA = distance corrected near visual acuity; EDoF = extended depth-of-focus; ERoV = extended range-of-focus; ESCRS = European Society of Cataract & Refractive Surgeons; GF = glisten free; I = intermediate; LCA = longitudinal chromatic aberration; N = near; T = toric available; — = unavailable data.
All visual acuities are measure in logarithm of the minimum angle of resolution. Pinhole and accommodative lenses are excluded here.
References to Table 1 appear online only (www.aaojournal.org).

regions of differing power can be created. The ReZoom IOL (see Table 1, row B3) and its predecessor, the Array IOL (Johnson & Johnson, previously Abbott Medical Optics), Santa Ana, CA), are examples of zonal concentric refractive multifocal IOLs.^{21,22} The M-flex refractive IOLs (Rayner, Sussex, United Kingdom; see Table 1, row E5) use alternate concentric areas of varying power to provide bifocality. Wavefront analysis and vergence maps can highlight the rapid changes of local power achieved throughout the pupil area (Fig 2). These regions do not need to be concentric disc portions: some designs include wedged regions, as with the Lentis Mplus IOL (Oculentis GmbH, Berlin, Germany; see Table 1, row E6).²³ These optical systems are dependent on pupil dynamics and sensitive to postoperative decentration, as well as the risk of causing photic phenomenon such as halos and glare. Reducing the power of the addition enables the conception of zonal refractive EDoF lenses such as the Lentis Comfort (Oculentis GmbH; see Table 1, row B2), which is designed to allow for activities further away than the reading distance.²⁴

Aspheric Lenses. Instead of correcting the spherical aberration, an aspherical surface can be used to produce a focus zone with low change in intensity and spot size. In this context, the modulation of the asphericity of the lens optic is designed to increase the depth of focus. This can be achieved by increasing the negative asphericity of the anterior or posterior surface of the IOL, generating a more negative spherical aberration as a result of the progressive shift in the local power from far to intermediate distance (Fig 3). Spherical aberration is a variation in focus position between rays as they move away from the optical axis. When negative, incoming parallel rays will focus further away as they are located away from the optical axis. Because of their smooth and continuous surface, aspheric lenses can extend the zone of focus within a range typically between 1 and 1.5 diopters (D). To be valuable for clinical application, the design of the lens should be robust to differing corneal asphericity and polychromatic light.

Extended depth-of-focus refractive lenses, such as the recently introduced Isopure (PhysIOL, Liège, Belgium; see Table 1, row A2) and Tecnis Eyhance (Johnson & Johnson, New Brunswick, NJ), use an aspheric design to increase negative aberration and achieve larger depth of focus compared with a monofocal lens.²⁵ They aim to provide patients with high-quality vision at far distances and improved vision at the intermediate distance. The optical design of such a lens requires the developer to take many variables into account, including the refractive index and base power. Complex polynomial design parameters are used to design the anterior and posterior surfaces.

It must be understood that aspheric EDoF lenses use asphericity primarily to increase the depth of focus as mentioned here previously. Other IOLs that have an aspheric design are made to compensate the corneal asphericity, which, in fact, reduces the eye's depth of focus because the total spherical aberration of the eye is reduced comparatively. Extended depth-of-focus IOLs based on asphericity have a more negative asphericity than that

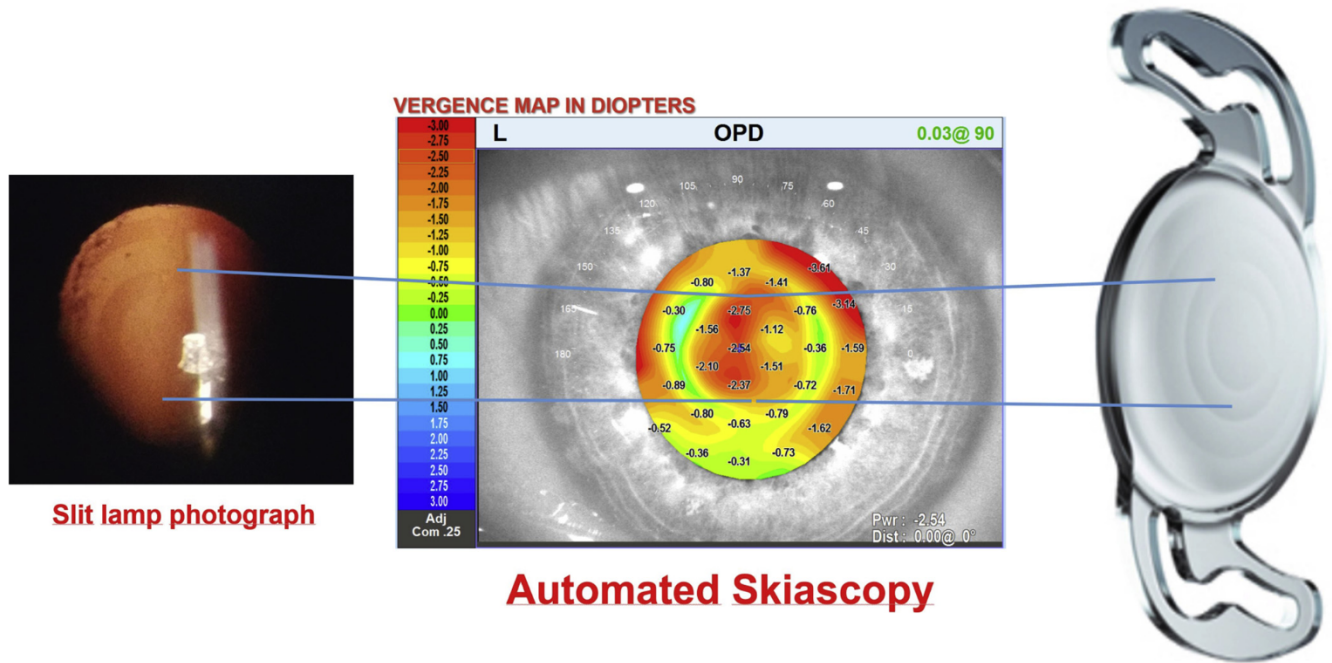


Figure 2. Slit-lamp images (left) and a vergence map (middle) obtained with automated skiascopy (OPD scan III; Nidek, Gamagori, Japan) after implantation of a bifocal refractive intraocular lens (IOL; M-flex [Rayner, Sussex, United Kingdom]; right). The refractive zones provide different powers that are responsible for the induced multifocality within the analyzed pupil area.

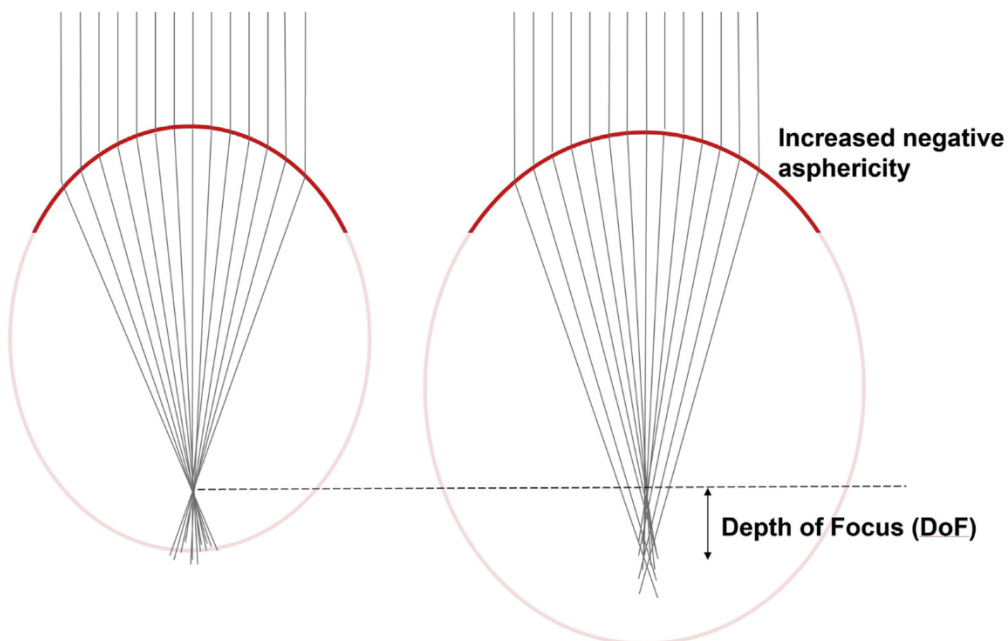


Figure 3. Diagram showing how increasing the negative asphericity of the anterior surface of an intraocular lens (IOL; outlined in red) free of aberrations while keeping its apical (paraxial) curvature constant will affect the refraction of the peripheral rays, which will be refracted further away from the paraxial focus as their angle of incidence is reduced because of the progressive surface flattening. This provides an extension of the focus zone at the expense of a reduction in the contrast of the image as a result of the effect of the defocused rays. This reduction can be minimized by limiting the depth of focus from distance to intermediate range of vision.

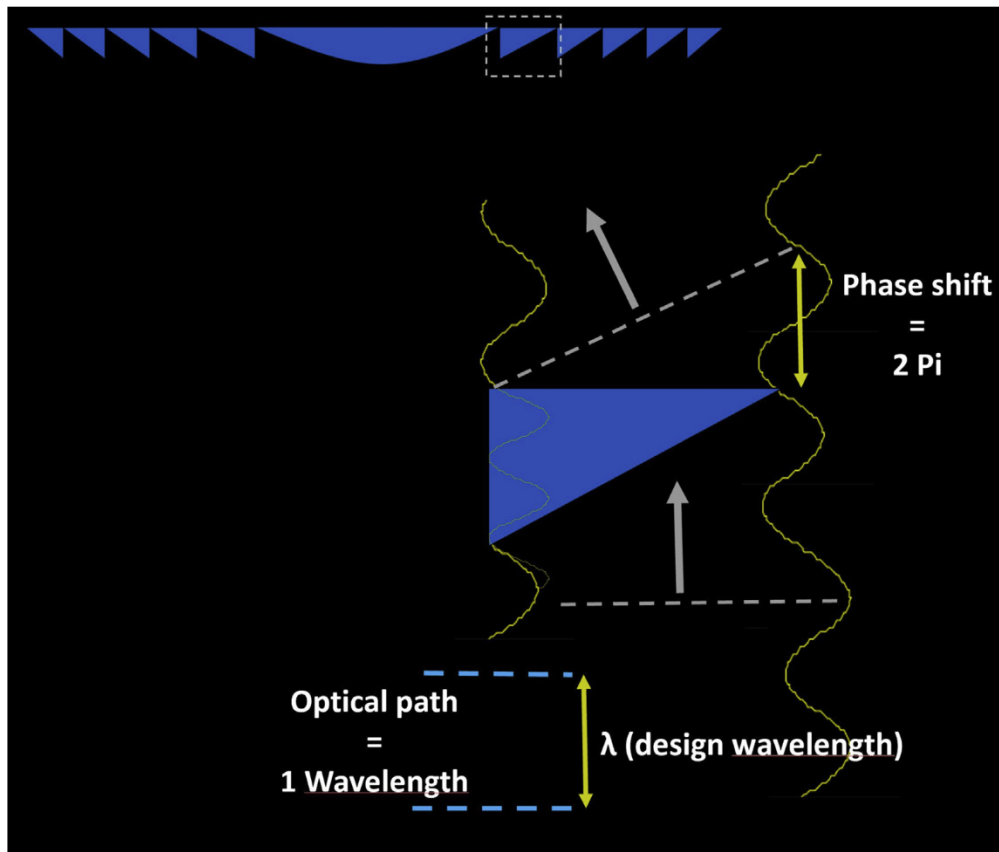


Figure 4. Schematic example in which the phase shift induced by a diffractive step is equal to 2π for the considered wavelength (optical path difference equals 1 wavelength). The maximum constructive interference at the output of the diffractive grating theoretically causes the deflection of the incident wavefront toward a single focus (diffraction order 1). For shorter wavelengths crossing the same diffractive steps, the phase shift would be longer than 2π , and this would generate the apparition of an additional foci corresponding to the second order of diffraction. The focal length of this second order of diffraction would be equal to half of the first-order foci focal length for that wavelength (the power/vergence would be double). For longer wavelengths, the phase shift would be shorter than 2π , and this would cause the diffraction of some of this incident light energy in the 0th order of diffraction.

needed to compensate (partly or fully) for the corneal spherical aberration.

Diffractive Intraocular Lenses

Diffractive IOLs use the optical phenomenon of diffraction to create multifocality. These optics often are misunderstood because they move away from the geometrical concept of light rays bending at the surface of the lens. These lenses take advantage of the wave nature of light. They create regions of constructive interference for the light waves propagating to the retina by selectively delaying the optical path (altering the phase relationships between the incoming light waves) in selected areas (Fig 4).

In diffractive IOLs, concentric annular zones are created on the anterior or posterior surface of the lens to constitute an asymmetrical zone plate, also called a *diffractive kinoform*.²⁶ As a gross approximation, the profile of the kinoform resembles an asymmetric saw-tooth profile. In practice, the height of these steps is just a few micrometers. This is somewhat expected because this scale is of the same order compared with that of the wavelength of the incoming light

within aqueous humor or lens material. Abrupt steps occur at the junction of each zone, and the spacing between the zones becomes progressively smaller from the center of the lens to its edge. The amount of light energy distributed on each focus is fully dependent on the diffractive structure of the IOL and the maximum height of the steps, the wavelength used, and the variation of the refractive index between the IOL material and its surrounding medium (Fig 5).

It is important to consider diffractive IOLs as the combination of a monofocal or toric base, which provides all or most of the refractive power of the implant, with a diffractive element, which enables the splitting of the incoming light into various foci: 2 main foci for bifocal IOLs and 3 for trifocal IOLs (Fig 6). Because of their discrete and repetitive structure, the diffractive elements create a finite number of noncontiguous focal points for the same incident light wavelength.

Another interesting property of diffractive elements is their wavelength dependence. They are designed to provide the desired multifocality for wavelengths located at the peak of retinal sensitivity (approximately 555 nm). However, in natural environments, light sources are polychromatic, and

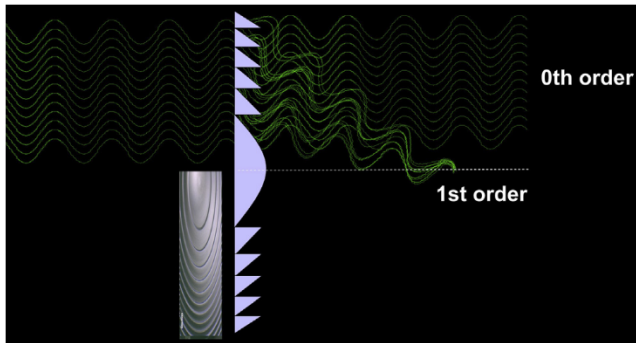


Figure 5. Schematic example showing diffraction by a diffractive element (kinoform). When the phase change is inferior to 2π for the considered wavelength in the surrounding medium, diffraction occurs in the 0th, first, and higher orders of diffraction (not shown here). The focusing distance of the wavefront corresponding to the first-order diffraction is a function of the width of the diffractive steps. For the second-order diffraction, the focusing distance is half of that of the first-order diffraction, and for the third-order diffraction, it is half of that of the second-order diffraction, and so forth.

specific chromatic effects are induced by diffractive IOLs, at least for some of the additional foci. Chromatic aberrations result from the failure of a lens to focus all colors to the same point. This dispersion is caused by variation of the refractive index of the lens elements with the wavelength of light: the refractive index of most transparent materials decreases with increasing wavelength. Because the focal length of a lens depends on the refractive index, this variation in refractive index affects focusing. However, the chromatic aberration of diffractive elements is of an opposite sign to that of refractive elements. In a diffractive driven focusing process, longer (red) wavelengths will be focused before shorter (blue) wavelengths (Fig 7). This property enables the compensation of the refractive chromatism in a hybrid refractive (carrier)—

diffractive IOL, at least for some its foci (Fig 8). The surface topographic features of a diffractive IOL can be measured to characterize their profiles, which have a strong impact on their optical properties. To understand further the basic concepts leading to the design of diffractive optics, one may start with the description of the basic properties of bifocal diffractive IOLs.

Bifocal Diffractive Intraocular Lenses. For a bifocal design, the radial distance of the n th zone occurs at $R_n = (nL \lambda_0 F)^{0.5}$, where λ_0 is the design wavelength (e.g., 555 nm), and F is the focal length (e.g., 0.25 m) of the corresponding add power $1 / F$ (e.g., +4 D).

The dimensions of the zones result in important optical properties, specifically for the design wavelength. Their width relates to the focal length of the add power: the higher the add (shorter focal length), the narrower the zones. For the same diameter, lenses with higher add power have more zones than those with lower add power. The height of the step at the boundary of each zone (grating amplitude) determines the split of light into the addition(s) via the induction of a phase delay.

A smaller percentage of the incoming light is diffracted into higher orders of diffraction (i.e., second, third) that have double and triple power values in comparison with the first-order add power, respectively. The diffractive efficiency describes the percentage of light going into each diffraction order.

A diffractive bifocal IOL, such as the Tecnis ZM900 (Johnson & Johnson) can be perceived as the hybridization of a monofocal carrier optic of +20 D with a diffractive bifocal element of +3.50 D of addition.²⁷ The height of the steps can be adjusted so that approximately 40% of the incoming light energy is directed into the 0th order (distance vision) and 40% into the first order (near addition). In such a design, approximately 5% of the incoming light is diffracted into the second order of diffraction at a foci of power $2 \times 4 = 8$ D. Hence, diffractive bifocal IOLs split light into more

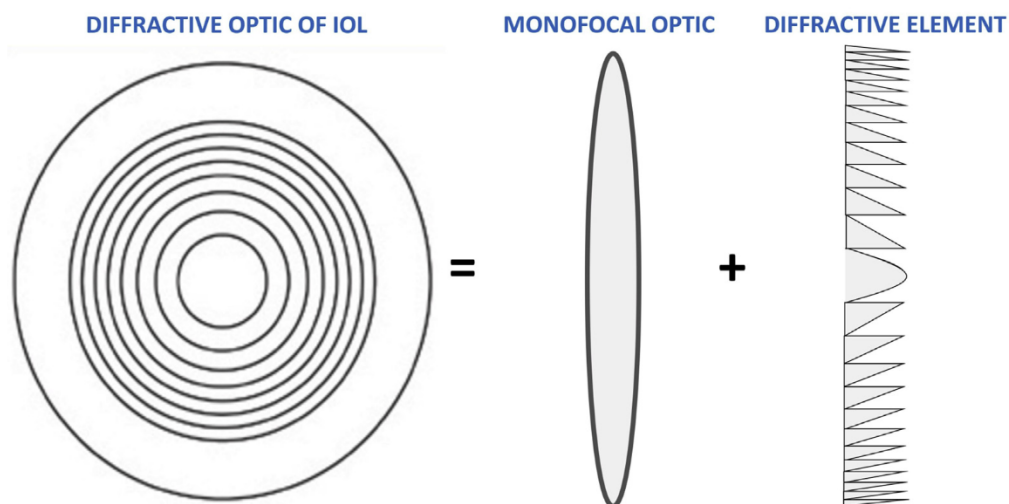


Figure 6. Schematic depiction of the anatomic features of a diffractive multifocal intraocular lens (IOL). The monofocal optic, which can be toric for astigmatism correction, is combined with a diffractive element, which can be added on the anterior or posterior surface of the optic. The light generated to multiple foci created by the diffractive element results from the combination of the monofocal carrier base power and the power addition(s) of the diffractive element.

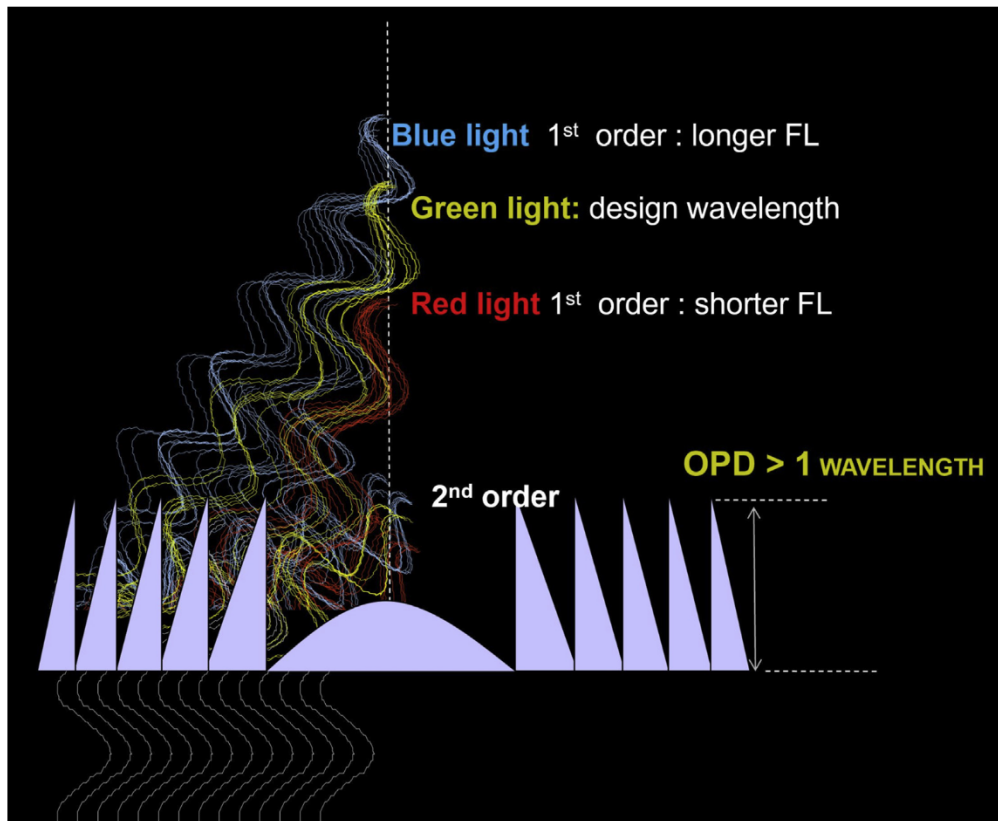


Figure 7. Schematic depiction of diffraction by a diffractive element designed to cancel the 0th order of diffraction (the maximal optical path differences [OPD] introduced by the diffractive steps is superior to 1 wavelength, shifting the phase of incoming wavefront portion by more than 2π). This introduces diffractive chromatism for each of the created foci, which may be used to reduce the inherent refractive chromatism of the monofocal carrier component. FL = focal length.

than 2 foci; however, they are designed so that the 2 visually useful foci (far and reading distance) receive most of the light energy. The Acri LISA IOL (Carl Zeiss Meditec AG, Jena, Germany) is designed to distribute twice the energy into the 0th order, as it does into the first order, to favor far vision.

The height of the steps can be reduced from the center of the optic to its periphery. This gradual decrease is called apodization (Fig 1, asterisk). It occurs within the diffractive structure of the ReSTOR IOL (Alcon Laboratories, Fort Worth, TX; see Table 1, row E1).^{5,27} These lenses have a diffractive bifocal structure covering their central 3 mm and are purely refractive in their periphery (distance vision). With such a design, although the net energy sent to the near and distance foci is nearly equal for small pupils, it is systematically shifted to a distance bias for larger pupil diameters. This characteristic helps to dampen stray light and halo effects for large pupils. Although apodization is beneficial for large pupils, with smaller or nonreactive pupils merely receiving the split light intended for distance vision, it is not an exclusion criterion necessarily.^{28,29}

The chromatic aberration at this focus is influenced by the diffractive nature of the light-focusing mechanism. The properties described here previously may give clinicians a solid foundation to understand the design features of some newer EDoF and trifocal IOLs.

Extended Depth-of-Focus Diffractive Intraocular Lenses. Although the power description of diffractive IOLs suggests maximum visual performance for distances corresponding to their distance and power addition, a gradual change occurs around these performance peaks. The Symphony IOL (Johnson & Johnson; see Table 1, row E3) can be described as a bifocal diffractive IOL with an add power of +1.75 D.³⁰ It consequently incurs a reduced number of diffractive zones (called *echellettes* by the manufacturer). The increased proximity between the main foci result in a steady optical performance, at least for small pupil apertures (Fig 9). This results in an EDoF from far- to intermediate-vision distances. Another interesting feature of the Symphony design results from the diffractive regimen that is achieved mainly using first- (far) and second- (intermediate) diffraction orders. This characteristic is obtained by increasing the height of the diffractive steps to introduce a phase delay longer than that corresponding to the design wavelength (2π), generating the amount of diffractive chromatism needed to balance the average corneal chromatism.

Trifocal Diffractive Intraocular Lenses. The first trifocal diffractive IOL, the FineVision lens (Physiol, Liège, Belgium; Table, 1, D3) was released in 2010.³¹ Its optical design resulted from the combination of 2 bifocal diffractive elements (Fig 10). The first diffractive element

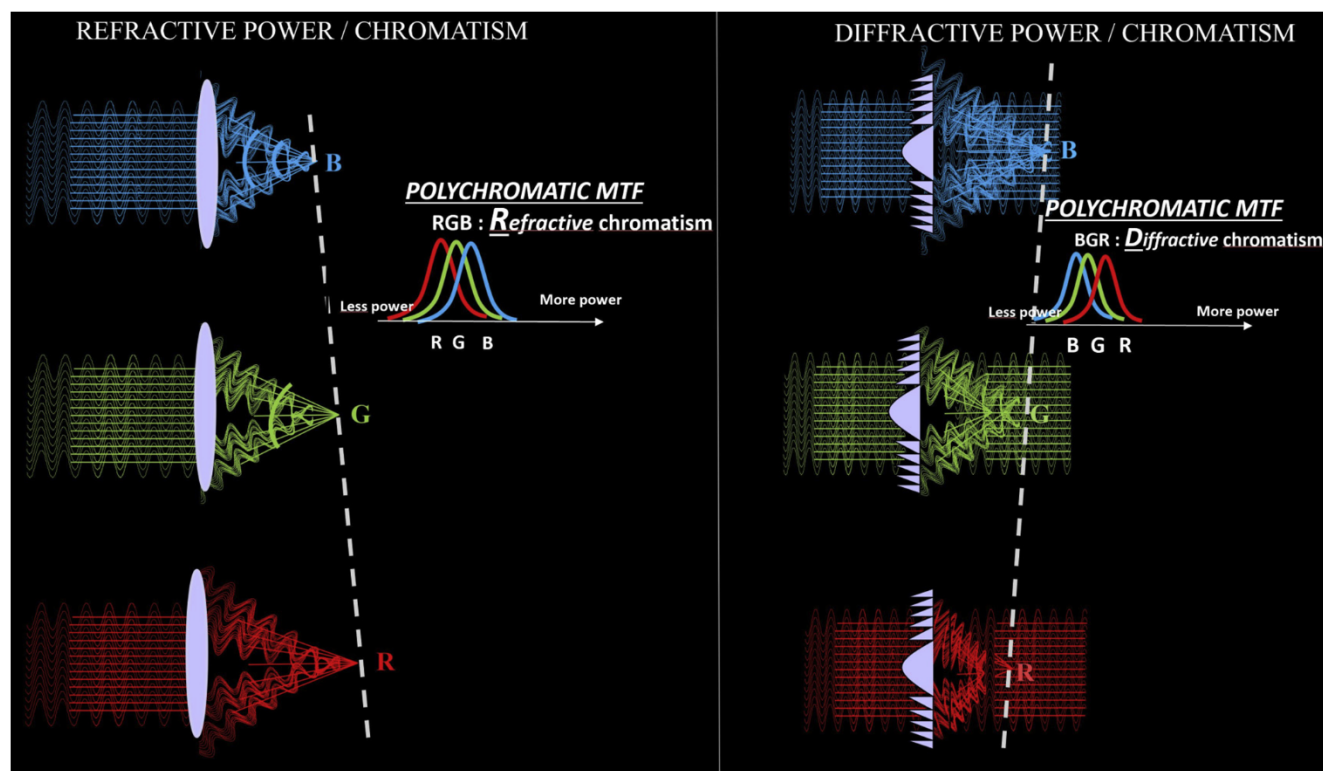


Figure 8. Schematic depiction of refractive (left) and diffractive (right) chromatism. The wavelength dependence of the refractive index of intraocular lens (IOL) materials causes a variation in the focus location: the power of the refractive element is higher for shorter wavelengths. Diffractive chromatism follows the opposite trend. The respective location of the peaks for red (R), green (G), and blue (B) light in the polychromatic modulation transfer function (MTF) curve provides information about the dominant process (refractive or diffractive) for each focus of interest generated by a multifocal IOL for the considered wavelength.

was designed with an add power of 3.5 D (near) in the first diffraction order. The second diffractive element provided an addition of 1.75 D (intermediate). Therefore, this diffractive element provided a faint (4.5% of incoming light) second diffraction order at a vergence of 3.50 D, which corresponds to light useful for near vision. The second order of this second diffractive pattern was used to reinforce approximately 5% of near vision (add +3.5 D), which mainly is afforded by the first order of the first diffractive pattern. As a result, the percentage of lost energy, which is usually 20% for standard diffractive bifocal lenses, was reduced with this IOL to approximately 14%. The IOL diffractive profile also was attenuated gradually throughout the entire optic (apodization), resulting in a continuous modulation of the light energy distribution, directed to the 3 primary foci. The larger the considered zone, the more light is directed proportionally to the distance foci. Because of the harmonic relationship between the intermediate and near foci (the latter having twice the vergence power of the intermediate), the total number of diffractive zones is unchanged compared with a bifocal IOL having the same near power, whereas the height of the diffractive steps alternates because of the superimposition of the intermediate diffractive profile.

Other trifocal IOLs have been introduced since. The AT LISA tri 839MP IOL (Carl Zeiss Meditec AG; see [Table 1](#),

row D2) uses a similar concept without apodization but with a diffractive zone limited to the central 4.5 mm of the optic.^{32,33} The RayOne trifocal IOL (Rayner; see [Table 1](#), row D5) is another trifocal optic in which the diffractive zone is constructed from the combination of 2 profiles that also are limited to the central 4.5 mm.³⁴

The AcrySof IQ Panoptix (Alcon Laboratories; see [Table 1](#), row D7) is a quadrifocal IOL with which one of the diffraction orders focusing in the long intermediate vision distance (1.1 D) range is suppressed.^{33–37} It provides a near addition power of +3.25 D and an intermediate vision power of +2.17 D. Its global diffractive design has a different rhythmicity than that of the FineVision (Physiol) and AT LISA tri IOLs, which reflects the indirect harmonic relationship between the near and intermediate foci.³²

Recently, a combination of the diffractive trifocal and EDoF technologies was incorporated in the design of the FineVision Triumf (see [Table 1](#), row C1) to improve intermediate vision, with the goal of reducing low-light condition side effects. The design of the implant uses the combination of 2 bifocal diffractive gratings, whose height is adjusted to favor the intermediate focus and to modulate chromatic aberration, while allowing the creation of a near foci of lesser energy. These gratings have globally higher steps and diffract mainly visible light in the first and second

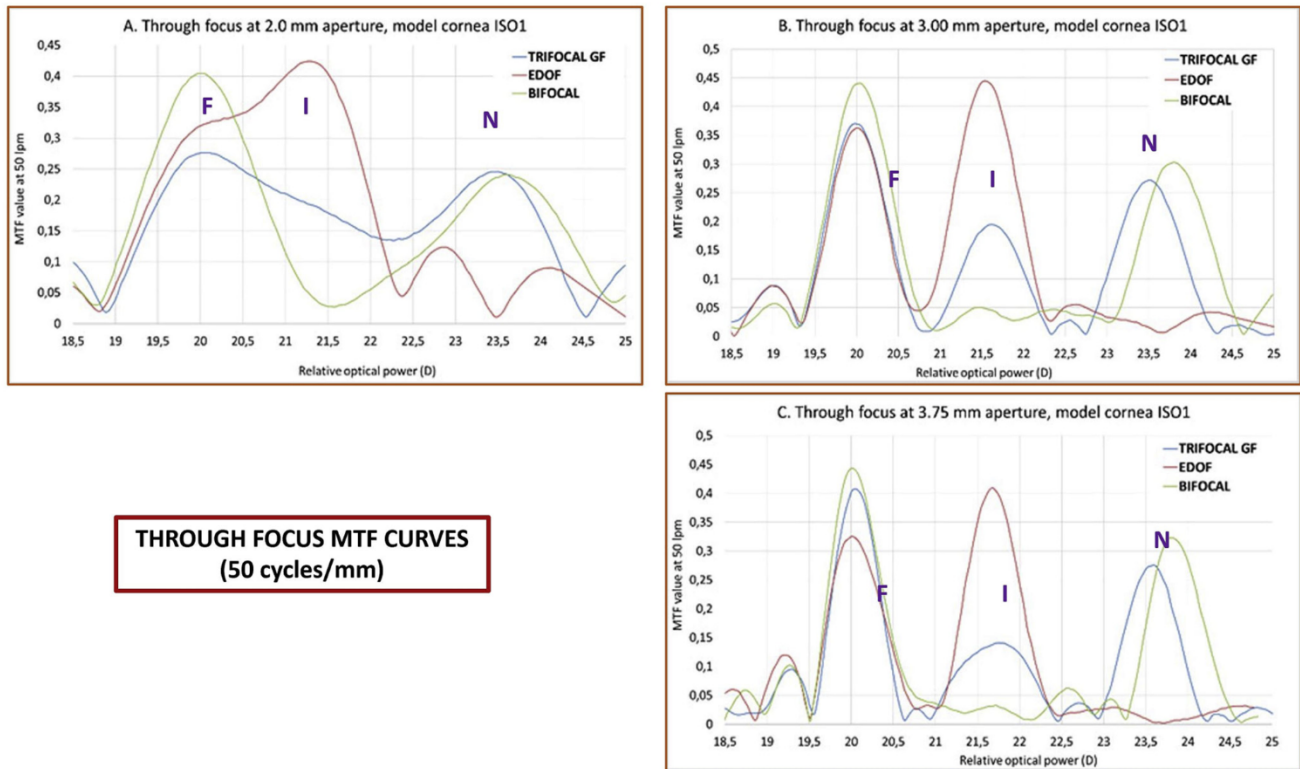


Figure 9. The through-focus modulation transfer function (MTF) curves of the 3 intraocular lenses (IOLs) collected at 50 cycles/mm and pupil apertures of 2.0 mm, 3.0 mm, and 3.75 mm are shown with the ISO 1 model cornea. At the 2.0-mm aperture, the extended depth-of-focus (EDoF) lens shows 2 partly overlapping MTF peaks at 2 focal points, +20.0 diopters (D) and +21.75 D, corresponding to far (F) and intermediate (I) vision distances in accordance with a power addition of +1.75 D. Similarly, the trifocal IOL shows partly merged MTF peaks for far and intermediate vision distances but displays an additional peak for near (N) vision at the +3.5-D power addition with respect to the distance vision power. As anticipated, the bifocal lens gives rise to 2 well-discriminated MTF peaks for distance and near vision with a power addition of +4.0 D. For pupil aperture larger than 2 mm, the MTF peaks become more discriminated, revealing the number and power positions of all focal points for a given optical design. The trifocal lens shows 3 MTF peaks for far, intermediate, and near distances and thus, 2 power additions of +1.75 D and +3.5 D with respect to the far focal point. The bifocal IOL seems to enhance far distance vision preferably, whereas in the EDoF lens, the intermediate distance vision seems to be dominant. Outcomes at the 3.75-mm pupil aperture are very similar to those obtained at 3.0 mm for the 3 lenses, when the same model cornea is used. The use of the ISO2 model cornea, with +0.28 μm spherical aberration (SA), for a same pupil aperture, is likely to result in slightly higher MTF at best focus for the far and reading distances, compared with its ISO1 counterpart (with 0 μm SA). In the case of EDoF and bifocal lenses, both have an SA of $-0.27 \mu\text{m}$ in contrast to the trifocal lens. Clearly, the EDoF lens enhances intermediate vision at +1.75 D addition, with MTF ranging between 0.41 and 0.45, regardless of the pupil aperture and cornea model. GF = glistering free.

order. The focus for far is not generated by the 0th order but rather by a combination of light refracted by the monofocal component and the diffraction in the first order. This corrects the chromatic aberrations for far and intermediate foci.

Refining Extended Depth-of-Focus Terminology

To examine specifically EDoF lenses, Table 2 was created to highlight the design and differences, putting forward a classification system to demystify this new subsection of premium IOLs. These lenses propose ways of elongating the continuous range of focus by 2 additional principles by using negative spherical aberration or the pinhole effect. Other additional, but not pure, EDoF effects, including diffractive EDoFs, that reduced chromatic aberrations allow increased contrast sensitivity, therefore

enhancing their function, although occasionally at the cost of some photic phenomenon.

With multifocal lenses, it is easier to understand what is being offered to the patients. Extended depth-of-focus IOLs, according to the American National Standards Institute (ANSI) standards, have to provide increased depth of focus compared with a monofocal IOL, with statistical superiority to monofocal lenses for photopic intermediate vision as well as being noninferior to the monofocal control at distance. Added confusion is created by various marketing phrases, including using the term *chelettes* for diffractive gratings (see Table 1, rows C2 and C3) or calling an IOL an even newer term, *continuous transitional focus*, when it really is a sectorial bifocal refractive lens and not at all a new concept (see Table 1, row C7).

Depth of focus extension per se can be achieved in only 2 ways: narrowing the aperture (as photographers do with the camera's diaphragm, such as with an IC8 lens) or using higher-order aberrations (HOAs) such as spherical

Trifocal technology – topology profile

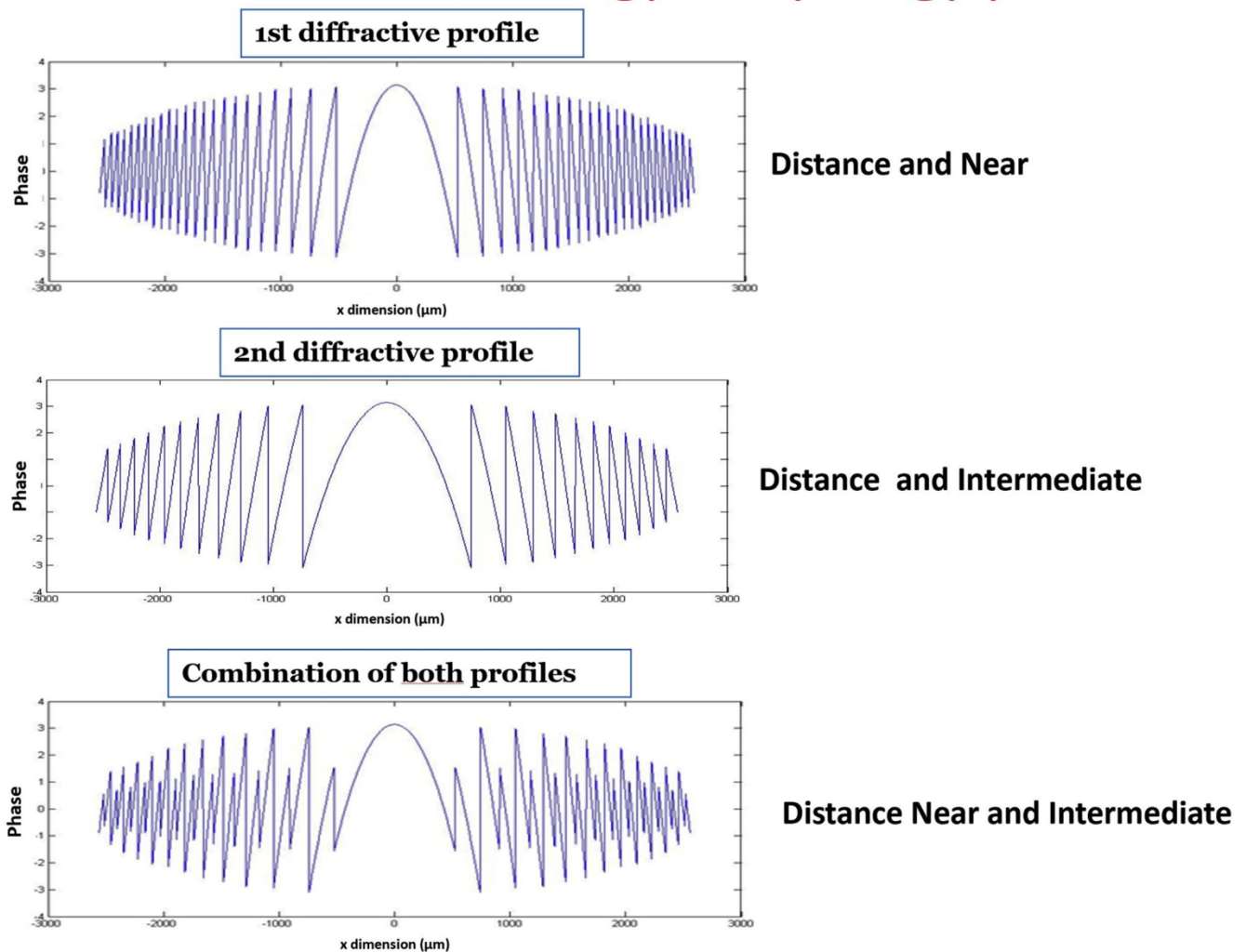


Figure 10. Schematic showing that a trifocal diffractive element can be achieved by combining 2 bifocal diffractive gratings. 2D = 2-dimensional.

aberration (e.g., Isopure or Vivity [Alcon Laboratories, Fort Worth, TX]). Any diffractive system relies on discrete foci generation (Symphony has been shown to be a bifocal distance and intermediate lens with chromatic compensation)¹⁷ and a zonal refractive system with discrete zones that also are providing discrete foci, as long as these zones are distinct. If the zones are blended (e.g., Vivity), it falls into the category of lenses using HOAs (there are no zones anymore but rather, a global zone with aspherical design).

The tables already illustrate this, but in relation to EDOFs, one would prefer a theoretical classification: (1) lenses with in vitro (optical design) and in vivo (visual) EDOF effects, that is, small apertures and aspherical continuous designs; and (2) lenses using discrete multiple foci to achieve an in vivo EDOF effect, that is, refractive zonal designs and diffractive designs.

As well as small aperture and aspherical designs, functionally efficient EDOF lenses also are based on a multifocal design. Many brands on the market are reluctant to label

these with the multifocal tag because of its association with photic symptoms. Even if multifocality is present, the modulation transfer function curve is blended by natural HOAs of the eye, added to an effect from pupil diffraction (especially if 2 mm or less) that then exhibits functional EDOF capacity. No pure continuous range of vision on the optical bench exists for discrete zonal and diffractive technologies. However, a discrete foci generation on the optical bench can still result in a full range of continuous vision.

Testing Intraocular Lenses (Optical Benches and Modulation Transfer Function Curves in Monochromatic and Polychromatic Lenses)

In vitro testing can provide rapid evaluation of IOLs in an environment similar to that of their implanted state and avoids

Table 2. Theoretical Extended Depth-of-Focus Nomenclature Proposal

Type of Intraocular Lens	Lens Model	Lens Feature			
		Small Aperture	Aspherical Continuous Designs	Refractive Zonal	Diffractive Design
True EDoF	IC-8	X			
	Morcher	X			
Enhanced monofocal	Vivity			X	
	Isopure		X		
	Xact				X
	Eyhance		X	X	
EDoF effect	Comfort			X	
	Rezoom			X	
	MiniWell Ready			X	
	Symfony				X
	Synergy				X
	Diff Aa			X	X
	Triumpf			X	X
	AT LARA				X

EDoF = extended depth-of-focus.

confounding factors of clinical testing, such as clarity of the cornea, retinal function, and neural processing.^{27,38} The aberrations of an IOL depend on the vergence of the light entering the implant; therefore, it is more relevant to test the optical performance of multifocal and EDoF IOLs with an artificial eye. It consists of an artificial cornea and a wet cell containing a saline solution into which the IOL is mounted.³⁹ The cornea is placed in front of the IOL and creates a converging beam that represents the vergence of the light entering the IOL. Model corneas can have null or predetermined levels of spherical aberration and chromatic dispersion. It is important to choose the best-suited artificial cornea for a specific context, because most multifocal and EDoF IOL designs use aspheric surfaces to dampen the average positive human corneal spherical aberration. An artificial pupil of adjustable diameter can be used to simulate the IOL behavior at differing pupil sizes.

The optical quality of IOLs can be assessed routinely by measuring the modulation transfer function, which describes the amount of contrast that is transmitted through the lens. If a high-contrast sinusoidal grating is imaged by an eye model equipped with the measured IOL, the contrast of the resultant image is reduced, and the contrast tends to reduce more severely with higher spatial frequency (i.e., the finer spacing of the bars of the sinusoidal target). Most of the in vitro optical characterizations have been performed in monochromatic green light. Using different monochromatic light sources enables exploration of the chromatic properties of an IOL, which are influenced by its design, refractive indices, and Abbe numbers (measurement of a material's dispersion; Fig 11A, B). The higher the Abbe number, the lower the chromatic aberration (high values indicate low dispersion).

Preoperative Planning

Counseling

As with any surgical intervention, one must plan meticulously by appropriate patient selection in consultation with a comprehensive preoperative assessment and in-depth counseling of the risks and benefits.^{3,40} Assess the patient's needs and personality; some negative patient factors are listed in Figure 12, along with a summary of preoperative assessments and possible postoperative adverse events.⁴¹

Surgeons must counsel the patient about adverse events, including halo, glare, and reduced contrast sensitivity, as well as discussing neuroadaptation in greater detail.^{32,42} A Cochrane review found photic phenomenon to be 3.5 times more likely in multifocal IOLs (decentration and posterior capsular opacification), with a 29% rate of residual ametropia, a 15% rate of dry eye, and a 54% rate of posterior capsular opacification.⁴¹ Before discussing the different compromises one makes when receiving a multifocal IOL, there should be an understanding that patients of any age have some natural photic phenomenon because of spectacles, contact lenses, or even the cataracts themselves, as well as their own eyes having naturally occurring HOAs. Although all lenses are susceptible to inducing negative dysphotopsias, multifocal IOLs have a higher chance of inducing positive dysphotopsia compared with monofocal lenses.^{43,44}

In patients for whom refractive laser surgery is not advised, motivation for spectacle independence may result from either presbyopia refractive error, with or without cataracts. These patients must be aware of all their initial options for IOLs, including monofocal IOLs with or without

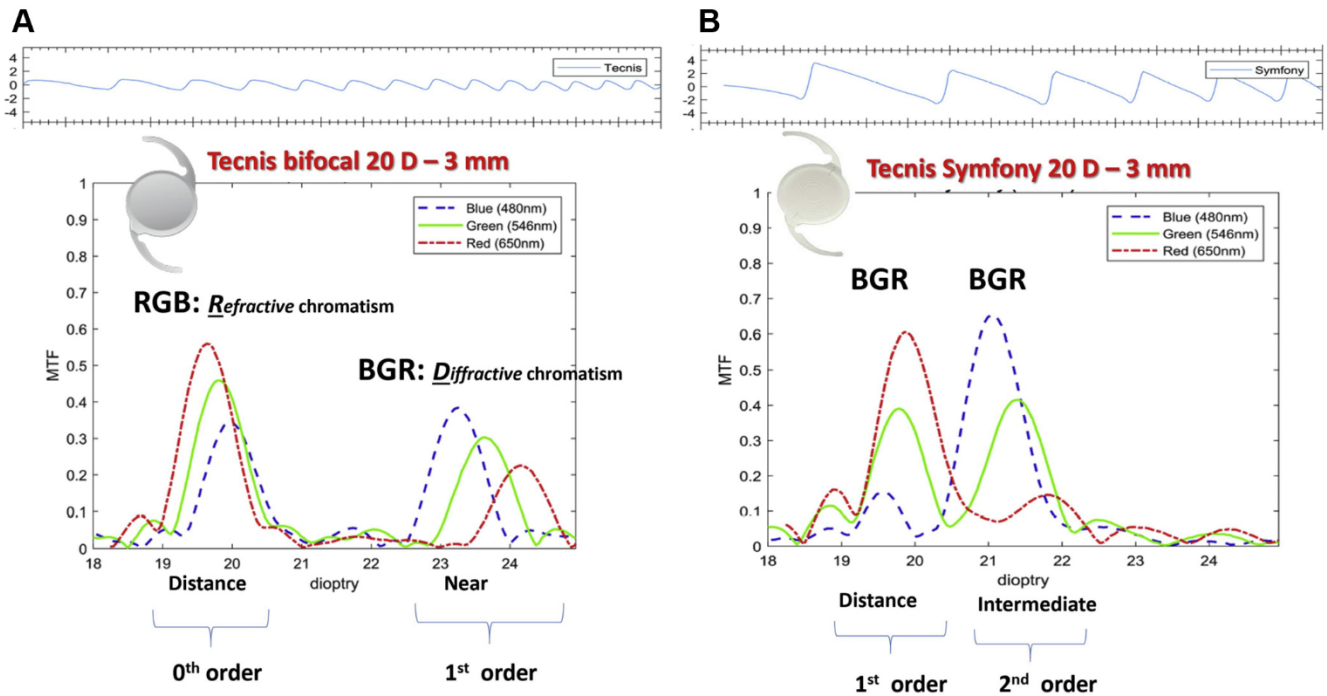


Figure 11. A, Graph showing that the Tecnis bifocal implant shares the light energy incident mainly between order 0 and order 1. The order 0 is focused thanks to the power of the monofocal carrier lens. The order of the peaks of the polychromatic modulation transfer function (MTF) curve is dictated by refractive chromaticism. Order 1 (focus of addition) is generated by a diffractive mechanism; the order of the peaks of the polychromatic MTF curve is dictated by diffractive chromaticism. B, Graph showing that the Tecnis Symphony implant shares the light energy incident mainly between the order 1 and the order 2. The order 1 is focused thanks to the power of the monofocal carrier lens and the addition of the diffractive grating. The order of the 2 main peaks of the polychromatic MTF curve is dictated by diffractive chromaticism. Order 2 creates an addition focus for intermediate vision. (Adapted from Loicq et al.¹⁷) B = blue; D = diopter; G = green; R = red.

toric correction and minimonovision or multifocal IOLs based on various optical platforms, to avoid lack of adequate informed consent.

To achieve spectacle independence and satisfaction, the clinician must understand their near and intermediate requirements with a detailed history of their work, hobbies, and lifestyle. Would they be accepting of spectacles for fine print, or do they drive at night for long periods, and are they able to understand fully that although the technology has advanced significantly, no perfect lens exists to simulate their presbyopic continuous vision. The patient is also counseled regarding potential required enhancement procedures. If the patient is able to understand all the information and is very motivated despite the range of risks and benefits presented, they could be a good candidate to take the conversation further.

Relative Contraindications

Many clinical factors may rule out the use of multifocal IOLs, including significant pre-existing ocular pathologic features precluding good visual potential after surgery. Multifocal IOLs are less likely to be recommended in patients who have severe untreated dry eyes (reduced tear film breakup time, punctate erosions, symptoms), Fuchs' endothelial dystrophy (guttata seen on slit lamp examination, reduced endothelial cell count, and increased pachymetry

values), severe macular degeneration or retinal disease (seen on OCT scan of the macula), advanced glaucoma (increased IOP, reduced visual fields), as well as patients with a multitude of type A personality traits (detailed patient history). Those who have high occupational visual demands, such as pilots or commercial drivers, are less suitable for these premium lenses. Topography allows for additional assessment of the posterior corneal astigmatism as well as tear film quality and corneal HOAs. Aberrometry is useful to assess the patient's preoperative HOA profile.

Avoidance of multifocal IOL in patients with pupillary abnormalities, such as corectopia or colobomas, is a step that may be overlooked, and its effects may be underestimated.⁴⁵ Measuring the angle κ value allows the prediction of increased dysphotopsia, and a large-angle κ value (>0.6 mm) is a potential contraindication, although experience may vary among types of lenses.⁴⁶ No signs should point toward a decentration risk in the patient, such as phacodonesis or pseudoexfoliation.

Previous Refractive Surgery

Because patients with previous refractive corneal surgery such as LASIK may be highly motivated to achieve spectacle independence after cataract surgery, it is important to review their eligibility after careful assessment and on a case-by-case basis.^{47,48} They still may be candidates for

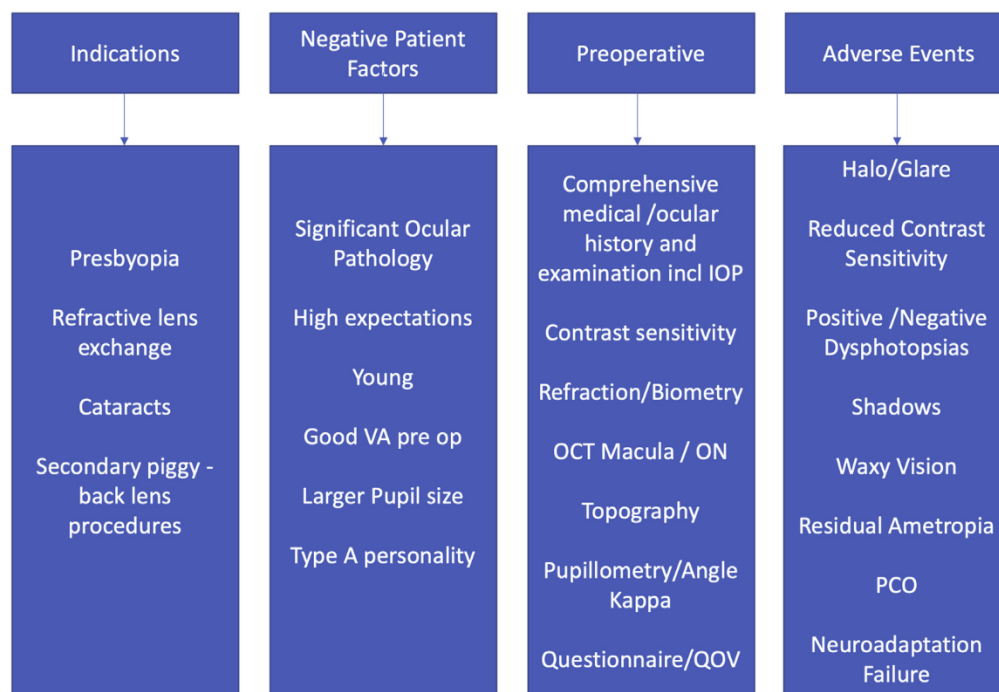


Figure 12. Diagram showing a summary of the indications, patient factors to consider before surgery, comprehensive assessment, and surgical planning for intraocular lens implantation. It also indicates adverse events that can occur after multifocal lens insertion.⁸⁶ IOP = intraocular lens; ON = optic nerve; PCO = posterior capsule opacification; QoV = quality of vision; VA = visual acuity.

multifocal lenses, with very few studies published. Conversely, they may benefit from either standard monofocal lenses with positive spherical aberration in the case of hyperopic LASIK or from aspheric IOLs with negative spherical aberrations in the case of myopic LASIK.⁴⁹ Patients who have undergone previous radial keratotomy who are reaching cataract age actually may benefit from a pinhole IOL strategy such as an IC8 (Acufocus, Irvine, CA) or Xtrafocus (Morcher GmbH, Germany) in the nondominant eye, although other EDoF lenses have produced reasonable results.^{50,51} These can also be considered in patients with corneal scarring or keratoconus (not discussed in this update).⁵² Patients with strabismus or dense amblyopia will find neuroadaptation challenging, and an orthoptic assessment is advised for these patients to assess suitability, as these features may be relative contraindications.⁵³

Lens Choice

After the patient is deemed suitable for the procedure, one must decide which of the multitude of multifocal IOLs is best suited to the patient's needs. For a multifocal IOL to be truly efficient, astigmatism must be totally neutralized, so astigmatism assessment and availability of toric versions is imperative with good rotational stability required (Toric versions where available, are marked with a T in brackets under the lens name within column 3; see Table 1).^{54,55} Patients with residual postoperative astigmatism beyond 0.5 to 0.75 D will be less likely to achieve an optimal

visual outcome, and a toric multifocal IOL is advised.^{55,56} When implanting a toric multifocal IOL, using a new-generation calculator, such as the Barrett (ascrs.org/tools/barrett-toric-calculator) or Physioltoric (physioltoric.eu) toric calculator,⁵⁷ and alignment using computational techniques⁵⁸ can ensure optimal neutralization. Large amounts of corneal astigmatism may benefit from a monovision, or a blended strategy with a monofocal toric IOL may be advised to avoid the negative effects of residual astigmatism. For much smaller amounts of astigmatism, on-axis incisions with the usual refractive surgical options are advised.

Besides pinhole, accommodative, or modular options, which are not discussed herein, options when implanting multifocal IOL lenses include bifocal lenses, trifocal lenses, EDoF lenses, or a mix-and-match approach. These could be refractive, diffractive, or a hybrid. Most surgeons prefer simultaneous bilateral insertion of the same multifocal IOLs, with the mix-and-match option using lenses of different types or designs to bridge the gap in the defocus curves binocularly, although this may not smooth out the curve completely and can cause unexpected photic phenomenon.¹³

To summarize the relevant decision making, albeit a simplification of the process, one can consider that bifocals give the best near vision but have a gap in intermediate vision that is filled by trifocal IOLs. Extended depth-of-focus lenses provide the least near vision and best intermediate vision with comparable photic phenomenon to trifocal IOLs (although the halo maybe more tolerable with

trifocals). Extended depth-of-focus IOLs suit patients who do not mind using spectacles for reading small print. Nonapodized diffractive lenses are pupil independent but sacrifice some intermediate vision and may induce more photic phenomenon. Refractive lenses provide a natural transition between distance and intermediate vision, near vision, or both, whereas diffractive lenses induce discrete foci (although in real life, any discontinuity between foci is neutralized to some extent by natural HOAs of the eye). Of note, hydrophilic lenses reduce stray light compared with hydrophobic lenses.^{13,59} With any lens choice, being prepared for neuroadaptation is key, and younger patients seem to adapt within a shorter period.⁵³ In most cases, attempts to match patient spherical aberrations with aspheric multifocal IOL designs help to limit the amount of postoperative HOAs.

Power Calculations

Lens power calculation is an important facet of surgical planning with multifocal IOLs. Although a minimal myopia is welcomed in the monofocal refractive outcomes, multifocal IOL designs have a low tolerance for this, instead preferring a hyperopic outcome that is nearest to emmetropia. Using newer-generation lens formulae and personalizing lens constants for a particular multifocal IOL is recommended.^{60,61} A shift could lead to an impractical reading vision range. As seen in Figure 12, a thorough examination including biometry is important. Use of intraoperative OCT after cataract removal could be useful in predicting the effective lens position, leading to superior lens calculations.⁶²

Risk of residual postoperative defocus must be discussed with patients. Options for postoperative refractive surprise include laser correction, add-on lenses, and, in certain cases, lens exchange, although the effective lens position remains a source of error.⁶³ For pupil size less than 2.5 mm, a refractive multifocal IOL may not be recommended.⁶⁴ Those with myopia are less dependent on spectacles for near and would prefer to avoid losing this ability to some extent.

Aside from patient factors, surgeon factors also play a role. A surgeon will implant lenses that they are comfortable with and are aware of their functional benefits and risks. As a novice, it is advisable to avoid extremely

demanding patients and is recommended that hyperopic patients be selected for the initial implantations, because those with myopia can underestimate their own spectacle independence for near vision, and an unhappy patient may result if appropriate planning is not carried out. When choosing a particular multifocal lens, we are satisfied by their safety profiles and reassured by their efficacy from published or presented materials. An established lens platform is easier to use with a reduced learning curve, as well as being informed by the experience of colleagues who may discover certain nuances of the lenses only appreciable when assessing one's own outcomes and postoperative patient interactions. A trustworthy company that has a reputation for advertising responsibly is also key.

Future of Multifocal and Extended Depth-of-Focus Intraocular Lenses

With rapid innovation in the field of IOL materials and design, the future looks promising (Fig 13).^{65–68} In the meantime, with advancement in surgical techniques (including femtosecond laser-assisted cataract surgery) and newer-generation IOL power calculations, we can see improved visual outcomes with currently available IOLs in the short term.^{69,70} Also, a potential number of devices are on the market and awaiting publication, including spectacle-mounted devices that may collect preoperative data regarding the patients' true distance, luminance, and usage data. We await publication data on this and from the range of newest EDoF lenses presented at conferences in 2019 (Table 1), as well as their longer-term study results for those currently on the market (Table S1, available at www.aaojournal.org).⁷¹

Ophthalmologists with an interest in multifocal IOLs are somewhat disappointed with the results of the first generation of accommodative IOLs, which were thought to work by changing the axial position of the IOL but in fact seem to work by changing the ocular aberration. Issues encountered with accommodative lenses include lens dislocation,^{72,73} capsular bag contraction syndrome, pseudoaccommodation, as well as a high rate of posterior capsular opacification.⁷⁴

Multifocal IOLs, including multifocal and EDoF IOLs, have successfully addressed the need for spectacle independence with distance, intermediate, and near vision in the

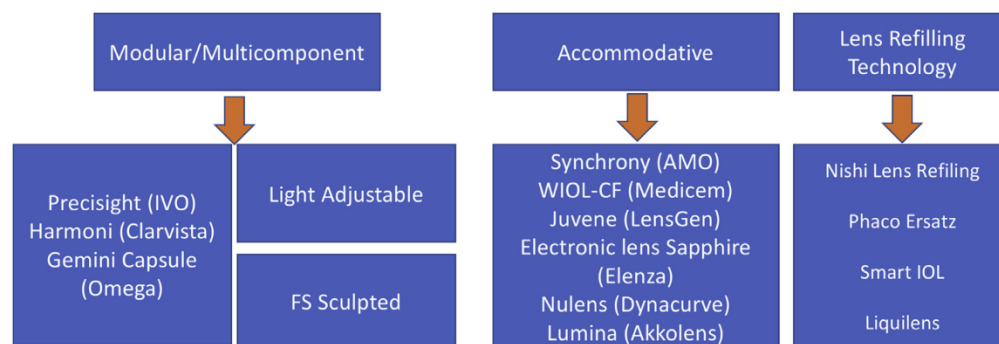


Figure 13. Diagram showing a summary of future intraocular lens (IOL) technologies.^{65–68} FS = femtosecond laser.

good-to-acceptable range with high satisfaction rates overall.^{4,75} Some limitations of earlier multifocal IOLs included high sensitivity to lens decentration, photic phenomenon, reduced contrast sensitivity, and an intolerance to the variable κ angle. Newer generations of EDoF IOLs are less affected by this, although it is still a concern. Extended depth-of-focus lenses provide superior continuous distance and intermediate vision but may be at the expense of near visual acuity.⁷⁶ Even if adverse events occur after implantation, most are reversible, including photorefractive keratectomy for residual ametropia and yttrium–aluminum–garnet laser capsulotomy for posterior capsular opacification. Intraocular lens exchange resulting from dissatisfaction despite appropriate time for neuroadaptation is a rare but serious outcome, and longer-term studies are required for both the established and newer generation of multifocal IOLs.^{77–79}

Patient-reported outcome measures are a key way to ensure that we have a standardized method of assessing patients after surgery. No consensus has been reached, with examples including the Freedom from Glasses Value Scale^{80,81} and the Near Activity Visual Questionnaire incorporating Rasch analysis.⁸² Automated systems, including the Halo & Glare Simulator (Eyeland-Design Network GmbH, Vreden, Germany), can be descriptive of the patient's perception of photic symptoms.⁸³ No society-led guidelines exist on methods of reporting patient-reported outcomes in patients with multifocal IOLs.

Much emphasis is placed on photic phenomena in studies investigating multifocal IOLs. From the studies listed in Table 1, it is clear that although a high percentage of patients experience some level of halos after surgery, for most of the participants, they are not significantly bothersome. Another issue to consider is the influence of multifocal IOLs on contrast sensitivity, which is not studied routinely after surgery but is a useful outcome measure to be standardized.⁸⁴

Conclusions

Relevant preoperative diagnostic evaluations, respect for patient selection criteria, appropriate counseling, and managing of expectations and underlying ocular intricacies are key to ensure success when implanting multifocal IOLs. Although the increasing availability of multifocal IOLs promotes understanding and research in this field to expand rapidly, we must be aware that novelty does not always equate to superiority.

Multifocal IOLs (including diffractive EDoFs) should remain as the umbrella term versus monofocal IOLs (including pinhole and aspheric lenses). Differentiating between lenses on the market while not losing sight of our main goal, which is to provide the right lens to the right patient, is possible with full counseling regarding what compromises patients are prepared to make to achieve multifocality according to their personal needs. Instead of bundling all the apparent EDoF IOLs together, one must look at their focality, optical principles, and practical features to allow the patient and surgeon to choose the correct lens.

A great debate is ongoing regarding EDoF lens nomenclature. Cornea and refractive surgeons must reach a global consensus regarding what are true theoretical or functional EDoF lenses. The American Academy of Ophthalmology task force has already developed several consensus statements for assessment of a full range of multifocal IOLs, including EDoF IOLs.^{12,14–16} With this task force and standardization of patient-reported outcome measures,⁸⁵ refractive cataract surgeons may be better equipped to evaluate and adopt selectively from the influx of innovation in the field of multifocal and EDoF IOLs.

References

1. Maurino V, Allan BD, Rubin GS, et al. Quality of vision after bilateral multifocal intraocular lens implantation. *Ophthalmology*. 2015;122:700–710.
2. Monaco G, Gari M, Di Censo F, et al. Visual performance after bilateral implantation of 2 new presbyopia-correcting intraocular lenses: trifocal versus extended range of vision. *J Cataract Refract Surg*. 2017;43:737–747.
3. Alio JL, Plaza-Puche AB, Fernández-Buenaga R, et al. Multifocal intraocular lenses: an overview. *Surv Ophthalmol*. 2017;62:611–634.
4. Khandelwal SS, Jun JJ, Mak S, et al. Effectiveness of multifocal and monofocal intraocular lenses for cataract surgery and lens replacement: a systematic review and meta-analysis. *Graefes Arch Clin Exp Ophthalmol*. 2019;257:863–875.
5. Pedrotti E, Carones F, Aiello F, et al. Comparative analysis of visual outcomes with 4 intraocular lenses: monofocal, multifocal, and extended range of vision. *J Cataract Refract Surg*. 2018;44:156–167.
6. Wilkins MR, Allan BD, Rubin GS, et al. Randomized trial of multifocal intraocular lenses versus monovision after bilateral cataract surgery. *Ophthalmology*. 2013;120:2449–2455.e1.
7. Labiris G, Giarmoukakis A, Patsiamanidi M, et al. Mini-monovision versus multifocal intraocular lens implantation. *J Cataract Refract Surg*. 2015;41:53–57.
8. Goldberg DG, Goldberg MH, Shah R, et al. Pseudophakic mini-monovision: high patient satisfaction, reduced spectacle dependence, and low cost. *BMC Ophthalmol*. 2018;18:293.
9. Greenstein S, Pineda 2nd R. The quest for spectacle independence: a comparison of multifocal intraocular lens implants and pseudophakic monovision for patients with presbyopia. *Semin Ophthalmol*. 2017;32:111–115.
10. Keates RH, Pearce JL, Schneider RT. Clinical results of the multifocal lens. *J Cataract Refract Surg*. 1987;13:557–560.
11. Vega-Estrada A, del Barrio JLA, Alió JL. Multifocal Intraocular Lenses: Accommodative intraocular lenses. *Essentials in Ophthalmology*. 2019:355–366.
12. MacRae S, Holladay JT, Glasser A, et al. Special report: American Academy of Ophthalmology task force consensus statement for extended depth of focus intraocular lenses. *Ophthalmology*. 2017;124:139–141.
13. Jiang Y, Bu S, Tian F, et al. Long-term clinical outcomes after mix and match implantation of two multifocal intraocular lenses with different adds. *J Ophthalmol*. 2019;2019:6789263.
14. Lum F, Holladay JT, Glasser A, et al. Special report: the American Academy of Ophthalmology task force for developing novel end points for premium intraocular lenses introduction. *Ophthalmology*. 2017;124:133–134.
15. Lum F, Tarver ME, Kahook MY, et al. Special commentary: Food and Drug Administration and American Academy

- of Ophthalmology sponsored. *Ophthalmology*. 2015;122:1522–1531.
16. Glasser A, Hilmantel G, Calogero D, et al. Special report: American Academy of Ophthalmology task force recommendations for test methods to assess accommodation produced by intraocular lenses. *Ophthalmology*. 2017;124:134–139.
 17. Loicq J, Willet N, Gatinel D. Topography and longitudinal chromatic aberration characterizations of refractive–diffractive multifocal intraocular lenses. *J Cataract Refract Surg*. 2019;45:1650–1659.
 18. Breyer DRH, Kaymak H, Ax T, et al. Multifocal intraocular lenses and extended depth of focus intraocular lenses. *Asia Pac J Ophthalmol (Phila)*. 2017;6:339–349.
 19. de Gracia P, de Gracia P, Dorronsoro C, et al. Experimental simulation of simultaneous vision. *Invest Ophthalmol Vis Sci*. 2013;54:415.
 20. Rosa AM, Miranda ÂC, Patrício M, et al. Functional magnetic resonance imaging to assess the neurobehavioral impact of dysphotopsia with multifocal intraocular lenses. *Ophthalmology*. 2017;124:1280–1289.
 21. Papadatou E, Del Águila-Carrasco AJ, Marín-Franch I, López-Gil N. Temporal multiplexing with adaptive optics for simultaneous vision. *Biomed Opt Express*. 2016;7:4102–4113.
 22. Cillino S, Casuccio A, Di Pace F, et al. One-year outcomes with new-generation multifocal intraocular lenses. *Ophthalmology*. 2008;115:1508–1516.
 23. Chiam PJ, Quah SA. The refractive outcome of Toric Lentis Mplus implant in cataract surgery. *Int J Ophthalmol*. 2016;9:699–702.
 24. Oshika T, Arai H, Fujita Y, et al. One-year clinical evaluation of rotationally asymmetric multifocal intraocular lens with +1.5 diopters near addition. *Sci Rep*. 2019;9:13117.
 25. Bilbao Calabuig R, Llovet Osuna V, Tejerina F. Isopure IOL: optical principles, optical bench results and first clinical outcomes of a new EDoF intraocular lens. Paper presented at: European Society of Cataract and Refractive Surgery, September 2019, Paris, France. Available at: <https://www.esrs.org/paris2019/programme/free-papers-details.asp?id=34116>; Accessed 05/11/2020.
 26. Moreno V, Román JF, Salgueiro JR. High efficiency diffractive lenses: deduction of kinoform profile. *Am J Physics*. 1997;65:556–562.
 27. Gatinel D, Houbrechts Y. Comparison of bifocal and trifocal diffractive and refractive intraocular lenses using an optical bench. *J Cataract Refract Surg*. 2013;39:1093–1099.
 28. Artigas JM, Menezo JL, Peris C, et al. Image quality with multifocal intraocular lenses and the effect of pupil size: comparison of refractive and hybrid refractive-diffractive designs. *J Cataract Refract Surg*. 2007;33:2111–2117.
 29. Knorz MC, Rincón JL, Suarez E, et al. Subjective outcomes after bilateral implantation of an apodized diffractive 3.0 D multifocal toric IOL in a prospective clinical study. *J Refract Surg*. 2013;29:762–767.
 30. Cochener B. Clinical outcomes of a new extended range of vision intraocular lens: International Multicenter Concerto Study. *J Cataract Refract Surg*. 2016;42:1268–1275.
 31. Gatinel D, Pagnouille C, Houbrechts Y, Gobin L. Design and qualification of a diffractive trifocal optical profile for intraocular lenses. *J Cataract Refract Surg*. 2011;37:2060–2067.
 32. Plaza-Puche AB, Alió JL. Analysis of defocus curves of different modern multifocal intraocular lenses. *Eur J Ophthalmol*. 2016;26:412–417.
 33. Tarib I, Diakonis VF, Breyer D, et al. Outcomes of combining a trifocal and a low-addition bifocal intraocular lens in patients seeking spectacle independence at all distances. *J Cataract Refract Surg*. 2019;45:620–629.
 34. Ferreira TB, Ribeiro FJ. Prospective comparison of clinical performance and subjective outcomes between two diffractive trifocal intraocular lenses in bilateral cataract surgery. *J Refract Surg*. 2019;35:418–425.
 35. Alió JL, Plaza-Puche AB, Alió Del Barrio JL, et al. Clinical outcomes with a diffractive trifocal intraocular lens. *Eur J Ophthalmol*. 2018;28:419–424.
 36. de Medeiros AL, de Araújo Rolim AG, Motta AFP, et al. Comparison of visual outcomes after bilateral implantation of a diffractive trifocal intraocular lens and blended implantation of an extended depth of focus intraocular lens with a diffractive bifocal intraocular lens. *Clin Ophthalmol*. 2017;11:1911–1916.
 37. Cochener B, Boutillier G, Lamard M, Auberger-Zagnoli C. A comparative evaluation of a new generation of diffractive trifocal and extended depth of focus intraocular lenses. *J Refract Surg*. 2018;34:507–514.
 38. Chen X, Chen Y, Fan J, et al. Development of a real time MTF test bench for visible optical systems. *Optical Design and Testing IV*. 2010. <https://doi.org/10.1117/12.870157>. Accessed 06/11/2020.
 39. Alba-Bueno F, Vega F, Millán MS. Design of a test bench for intraocular lens optical characterization. *J Physics Conf Ser*. 2011;274:012105.
 40. Clark A, Morlet N, Ng JQ, et al. Whole population trends in complications of cataract surgery over 22 years in Western Australia. *Ophthalmology*. 2011;118:1055–1061.
 41. de Silva SR, Evans JR, Kirthi V, et al. Multifocal versus monofocal intraocular lenses after cataract extraction. *Cochrane Database Syst Rev*. 2016;12:CD003169.
 42. Al-Shymali O, Alió JL. Multifocal intraocular lenses: neuroadaptation failure corrected by exchanging with a different multifocal intraocular lens. *Essentials in Ophthalmology*. 2019:111–119.
 43. Erie JC, Bandhauer MH, McLaren JW. Analysis of post-operative glare and intraocular lens design. *J Cataract Refract Surg*. 2001;27:614–621.
 44. Tester R, Pace NL, Samore M, Olson RJ. Dysphotopsia in phakic and pseudophakic patients: incidence and relation to intraocular lens type. *J Cataract Refract Surg*. 2000;26:810–816.
 45. LoBue SA, Mano F, Schaefer E, LoBue TD. Unilateral multifocal intraocular lens implantation in a patient with Adie’s pupil. *Case Rep Ophthalmol*. 2018;9:369–374.
 46. Fu Y, Kou J, Chen D, et al. Influence of angle kappa and angle alpha on visual quality after implantation of multifocal intraocular lenses. *J Cataract Refract Surg*. 2019;45:1258–1264.
 47. Chow SSW, Chan TCY, Ng ALK, Kwok AKH. Outcomes of presbyopia-correcting intraocular lenses after laser in situ keratomileusis. *Int Ophthalmol*. 2019;39:1199–1204.
 48. Vrijman V, van der Linden JW, van der Meulen IJE, et al. Multifocal intraocular lens implantation after previous hyperopic corneal refractive laser surgery. *J Cataract Refract Surg*. 2018;44:466–470.
 49. Benito A, Redondo M, Artal P. Laser in situ keratomileusis disrupts the aberration compensation mechanism of the human eye. *Am J Ophthalmol*. 2009;147:424–431.e1.
 50. Baartman BJ, Karpuk K, Eichhorn B, et al. Extended depth of focus lens implantation after radial keratotomy [reply]. *Clin Ophthalmol*. 2019;13:1647–1648.
 51. Agarwal S, Thornell E. Spectacle independence in patients with prior radial keratotomy following cataract surgery: a case series. *Int Med Case Rep J*. 2020;13:53–60.

52. Hooshmand J, Allen P, Huynh T, et al. Small aperture IC-8 intraocular lens in cataract patients: achieving extended depth of focus through small aperture optics. *Eye*. 2019;33:1096–1103.
53. Alió JL, Píkkel J. *Multifocal Intraocular Lenses: The Art and the Practice*. Springer Nature; 2019.
54. Alió JL, Píkkel J. Multifocal intraocular lenses: preoperative considerations. *Essentials in Ophthalmology*. 2019;43–52.
55. Kessel L, Andresen J, Tendal B, et al. Toric intraocular lenses in the correction of astigmatism during cataract surgery: a systematic review and meta-analysis. *Ophthalmology*. 2016;123:275–286.
56. Ang RE. Small-aperture intraocular lens tolerance to induced astigmatism. *Clin Ophthalmol*. 2018;12:1659–1664.
57. Ribeiro FJ, Ferreira TB, Relha C, et al. Predictability of different calculators in the minimization of postoperative astigmatism after implantation of a toric intraocular lens. *Clin Ophthalmol*. 2019;13:1649–1656.
58. Kim EC, Hwang KY, Lim SA, et al. Accuracy of toric intraocular lens implantation using automated vs manual marking. *BMC Ophthalmol*. 2019;19:169.
59. van der Linden JW, van der Linden JW, van der Meulen IJ, et al. Comparison of a hydrophilic and a hydrophobic apodized diffractive multifocal intraocular lens. *Int Ophthalmol*. 2013;33:493–500.
60. Melles RB, Holladay JT, Chang WJ. Accuracy of intraocular lens calculation formulas. *Ophthalmology*. 2018;125:169–178.
61. Reitblat O, Assia EI, Kleinmann G, et al. Accuracy of predicted refraction with multifocal intraocular lenses using two biometry measurement devices and multiple intraocular lens power calculation formulas. *Clin Exp Ophthalmol*. 2015;43:328–334.
62. Posarelli C, Sartini F, Casini G, et al. What is the impact of intraoperative microscope-integrated OCT in ophthalmic surgery? Relevant applications and outcomes. A systematic review. *J Clin Med Res*. 2020;9:1682.
63. Sáles CS, Manche EE. Managing residual refractive error after cataract surgery. *J Cataract Refract Surg*. 2015;41:1289–1299.
64. Ouchi M, Shiba T. Diffractive multifocal intraocular lens implantation in eyes with a small-diameter pupil. *Sci Rep*. 2018;8:11686.
65. Uy HS, Tesone-Coelho C, Ginis H. Enhancement-procedure outcomes in patients implanted with the Precisight multicomponent intraocular lens. *Clin Ophthalmol*. 2019;13:107–114.
66. SooHoo JR, Lane SS, Cionni RJ, et al. Comparison of stability between a modular intraocular lens system and a single-piece hydrophobic acrylic intraocular lens. *J Cataract Refract Surg*. 2016;42:1821–1825.
67. Moshirfar M. Astigmatic correction with implantation of a light adjustable vs monofocal lens: a single site analysis of a randomized controlled trial. *Int J Ophthalmol*. 2019;12(7):1101–1107.
68. Nishi Y, Mireskandari K, Khaw P, Findl O. Lens refilling to restore accommodation. *J Cataract Refract Surg*. 2009;35:374–382.
69. Žiak P, Halička J, Mojžiš P, et al. Presbyopic lens exchange (PRELEX) cataract surgery outcomes with implantation of a rotationally asymmetric refractive multifocal intraocular lens: femtosecond laser-assisted versus manual phacoemulsification. *Int Ophthalmol*. 2019;39:2875–2882.
70. Lee JA, Song WK, Kim JY, et al. Femtosecond laser-assisted cataract surgery versus conventional phacoemulsification: refractive and aberrometric outcomes with a diffractive multifocal intraocular lens. *J Cataract Refract Surg*. 2019;45:21–27.
71. Sieburth R, Chen M. Intraocular lens correction of presbyopia. *Taiwan J Ophthalmol*. 2019;9:4–17.
72. Lee YH, Kim YC. In-the-bag dislocation of polyfocal full-optics accommodative intraocular lens: a case report. *Indian J Ophthalmol*. 2019;67:1200–1202.
73. Kim YC, Kang KT, Yeo Y, et al. Consistent pattern in positional instability of polyfocal full-optics accommodative IOL. *Int Ophthalmol*. 2017;37:1299–1304.
74. Pepose JS, Burke J, Qazi MA. Benefits and barriers of accommodating intraocular lenses. *Curr Opin Ophthalmol*. 2017;28:3–8.
75. Zvorničanin J, Zvorničanin E. Premium intraocular lenses: the past, present and future. *J Curr Ophthalmol*. 2018;30:287–296.
76. Domínguez-Vicent A, Esteve-Taboada JJ, Del Águila-Carrasco AJ, et al. In vitro optical quality comparison of 2 trifocal intraocular lenses and 1 progressive multifocal intraocular lens. *J Cataract Refract Surg*. 2016;42:138–147.
77. Wang SY, Stem MS, Oren G, et al. Patient-centered and visual quality outcomes of premium cataract surgery: a systematic review. *Eur J Ophthalmol*. 2017;27:387–401.
78. Rudalevicius P, Lekaviciene R, Auffarth GU, et al. Relations between patient personality and patients' dissatisfaction after multifocal intraocular lens implantation: clinical study based on the five factor inventory personality evaluation. *Eye*. 2020;34:717–724.
79. Woodward MA, Randleman BJ, Stulting DR. Dissatisfaction after multifocal intraocular lens implantation. *J Cataract Refract Surg*. 2009;35:992–997.
80. Lévy P, Elies D, Dithmer O, et al. Development of a new subjective questionnaire: the Freedom from Glasses Value Scale (FGVS). *J Refract Surg*. 2010;26:438–446.
81. Berdeaux G, Meunier J, Arnould B, Viala-Danten M. Measuring benefits and patients' satisfaction when glasses are not needed after cataract and presbyopia surgery: scoring and psychometric validation of the Freedom from Glasses Value Scale (FGVS©). *BMC Ophthalmol*. 2010;10.
82. Buckhurst PJ, Wolffsohn JS, Gupta N, et al. Development of a questionnaire to assess the relative subjective benefits of presbyopia correction. *J Cataract Refract Surg*. 2012;38:74–79.
83. Kretz FTA, Breyer D, Klabe K, et al. Clinical outcomes after implantation of a trifocal toric intraocular lens. *J Cataract Refract Surg*. 2015;31:504–510.
84. Alió JL, Kaymak H, Breyer D, et al. Quality of life related variables measured for three multifocal diffractive intraocular lenses: a prospective randomised clinical trial. *Clin Exp Ophthalmol*. 2018;46:380–388.
85. Maxwell A, Holland E, Cibik L, et al. Clinical and patient-reported outcomes of bilateral implantation of a +2.5 diopter multifocal intraocular lens. *J Cataract Refract Surg*. 2017;43:29–41.
86. Braga-Mele R, Chang D, Dewey S, et al. Multifocal intraocular lenses: relative indications and contraindications for implantation. *J Cataract Refract Surg*. 2014;40:313–322.

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Abbreviations and Acronyms:

ANSI = American National Standards Institute; **D** = diopter; **EDoF** = extended depth-of-focus; **ESCRS** = European Society of Cataract & Refractive Surgery; **FS** = femtosecond laser; **GF** = glistening free; **HOA** = higher-order aberration; **IOL** = intraocular lens; **IOP** = intraocular pressure; **LASIK** = laser assisted in situ keratomileusis; **logMAR** = logarithm of the minimum angle of resolution; **MTF** = modulation transfer function; **OPD** = optical path difference; **PCO** = posterior capsular opacification; **QoV** = quality of vision; **SA** = spherical aberration.

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