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Intraocular lens correction of presbyopia

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Abstract:

The continued development of intraocular lens (IOL) technology has led to a dramatic improvement in refractive outcomes. New and innovative ways of achieving the desired postoperative refractive goals continue to be developed. This article aims to review the currently available IOL modalities for correction of presbyopia at the time of cataract surgery, including reference to high-quality comparative studies, where available, and discussion of strengths as well as limitations of the currently available IOL technologies. It has been shown that multifocal compared to monofocal IOL was associated with higher rates of spectacle independence, but higher rates and severity of symptomatic glare as well as reduced contrast sensitivity. Within multifocal IOLs, diffractive compared to refractive IOLs tended to have better near vision and a lower rate of symptomatic glare. Extended depth-of-focus IOLs compared to diffractive multifocal IOL demonstrated equal or superior intermediate visual acuity, with less than or equal rates of glare. Accommodative IOLs represent a broad range of technologies that continue to develop, and new technologies offering opportunities for postoperative adjustment of refractive outcome are emerging.

Keywords:

Accommodative intraocular lens, cataract surgery, extended depth-of-focus intraocular lens, intraocular lens, intraocular lens technology, lens, multifocal intraocular lens, premium cataract surgery, presbyopia correction, refractive cataract surgery

Introduction

Cataract is estimated to affect 52.6 million people worldwide and is globally estimated to cause 33% of total visual impairment and 51% of total blindness.[1,2] With 83% of total cases of blindness considered to be preventable, cataract is the number one cause not only of blindness but of preventable blindness globally.[1,2] As major efforts continue to reduce this disease burden, with increasing rates of cataract surgery and improving refractive postoperative outcomes, rates of global blindness due to cataract have been declining.[3] As paradigms in management strategy for patients with cataract shift from a focus on anatomic resolution of disease toward patient-centered care responsive to individual patient wants and needs, refractive considerations are increasingly important in preoperative evaluation and surgical planning.[4] Patients not accustomed to corrective spectacle wear preoperatively tend to have greater expectations of postoperative spectacle independence for both distance and near vision after cataract surgery.[5] Due to the popular desire for spectacle independence postoperatively, use of intraocular lens (IOL) for presbyopia correction in the setting of cataract surgery is an increasingly prevalent aspect of premium cataract surgery practice. IOL technology has advanced significantly over the past several decades, and an increasingly diverse set of options for IOL correction of presbyopia has become available to physicians. An understanding of the relative strengths and weaknesses of each IOL technology is fundamental to proper patient selection, preoperative counseling, and surgical planning. This review describes

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current IOL technology for presbyopia correction in cataract surgery, quality comparative information where available, and new IOL technologies currently in development.

Monovision

Monofocal IOLs are spherical IOLs that produce focus at one point. Historically, both eyes have often been set for the same refractive target. Some patients may prefer emmetropia for distance, with use of reading glasses for near work, but others may prefer to be free of spectacles for reading, relying instead on corrective lenses for distance. In cases of nonrefractive low vision such as advanced macular degeneration, a patient may desire induction of high myopia with cataract surgery to obviate the necessity for the use of low-vision aides for reading. For correction of presbyopia, use of monofocal IOLs to create “monovision” has long been a popular choice for select patients. Monovision is created with induction of monocular myopia for near or intermediate work. The “dominant” eye is chosen using the Miles test, and that eye is often targeted for emmetropia. Trial contact lens inducing myopia in the nondominant eye should be performed preoperatively to ensure tolerance of anisometropia and associated aniseikonia prior to undergoing cataract surgery with a monovision target. Limitations of monovision include interference with stereoacuity, aniseikonia, subjective visual disturbance, and limitation to use only in the population of patients tolerant of induction of monovision.

Multifocal Intraocular Lens

The first of its kind, multifocal IOLs for correction of presbyopia were first implanted in human eyes in 1986 but were initially slow to be widely adopted.[6,7] A large variety of multifocal IOLs have been developed. Although early models such as the BioFilmCon have been discontinued, many multifocal IOLs remain widely available worldwide, though only a select few have been Food and Drug Administration (FDA) approved for sale in the United States [Table 1].[8,9] Multifocal IOLs may be categorized as refractive and diffractive as well as bifocal and trifocal. Refraction and diffraction refer to the physical mechanism used by the lens to cause bundling of light at distinct points.[10] IOLs may have both refractive and diffractive design components. Bifocal and trifocal describe the number of distinct focal points at which this light is bundled. Simultaneous perception of disparate images from these multiple focal points can be initially disturbing to patients and require a months-long period of neuroadaptation postoperatively.[11] Certain lenses are rotationally asymmetric, with an inferior segment containing the refractive power required for good near vision; positioning of this segment inferiorly, superiorly, temporally, or nasally has not been found to significantly affect visual performance.[12] Extended depth of focus (EDOF) refers to a longitudinally extended continuous focal point and is discussed separately.

Refractive

Progressive or zonal refractive multifocal IOLs use concentric zones of increasing dioptric power on the anterior lens surface, with highest dioptric power at the center of the lens. The goal of this design is to increase accommodative power in response to miosis with the near reflex, as a smaller pupil will allow light to pass through those refractive zones with higher dioptric power located at the center of the lens. The distribution of light passing through the lens varies between distance and near according to variation in pupil size. For example, an analysis of the bifocal refractive AMO Array SSM 26NB IOL demonstrated 50%–60% light allocation for distance, 22%–38% for near, and 15%–18% at intermediate foci.[13]

Diffractive

Diffractive IOLs rely on concentric diffractive surfaces on the posterior portion of the lens; this causes interference of optic wavefronts, designed such that interference between diffracted light rays may reduce but remains incapable of eliminating glare and higher order aberrations associated with multifocal IOLs. Apodized diffractive IOLs, such as progressive refractive IOLs, rely on pupil size to influence light distribution between distant and near focal points. Again, light passing through the lens is distributed between distance, near, and other foci. For example, the first ever 3 M diffractive bifocal IOL allocates 41% of incident light to distance and near focus, with 18% of light distributed to higher order diffraction.[13]

Refractive compared to diffractive

Refractive compared to diffractive IOLs tend to have greater frequency of symptomatic glare, haloes, and higher order aberrations.[14] Meta-analysis demonstrates refractive multifocal IOL tend to produce better-uncorrected distance visual acuity (UDVA) compared to diffractive multifocal IOL.[14] Diffractive multifocal IOL performed better than the refractive multifocal IOL in uncorrected near visual acuity (UNVA), reading acuity, reading speed, smallest print size, spectacle independence, halo, and glare rate.[14] There was no significant difference between the two groups with regard to uncorrected intermediate visual acuity (UIVA).[14]

Apodized versus nonapodized diffractive and progressive versus nonprogressive refractive

Apodized diffractive and progressive or zonal refractive IOLs rely on pupil size changes to mimic accommodation, whereas constant multifocal lenses have the same optical property over the entire optic surface. It is important to note that IOL decentration and pupil size affect

Table 1: Multifocal Intraocular Lenses

Manufacturer	IOL brand	IOL model	Material	Pieces	Haptic design	Haptic angulation (degrees)	IOL (mm)	Optic (mm)	Focallity	Optical Principle	Symmetry	Structure	Intermed add (D)	Near add (D)	Incision Size (mm)	FDA Approved	Pupil Dependence	Location	Toric version
1st Q	AddOn	AddOn Progressive	Hydrophobic acrylis	1	Square, 4-flex haptics	Not published	13.0	6.0	Bifocal	Diffractive	Rotationally symmetric, convex -concave	Apodized	0	+3.00	Not published	No	Yes	Sulcus	Yes
	Basis	BasisQ	Hydrophilic acrylic with hydrophobic surface	1	4 double -loop haptics	0	13.0	6.0	Bifocal	Diffractive	Rotationally symmetric	Apodized	0	+3.0 or+3.5	Not published	No	Yes	Bag	No
	Basis	BasisZ	Hydrophilic acrylic with hydrophobic surface	1	Z-loop haptics	0	13.0	6.0	Bifocal	Diffractive	Rotationally symmetric	Apodized	0	+3.50	Not published	No	Yes	Bag	Yes
Aaren scientific	Aquavis	OptiVis MF	Hydrophilic acrylic	1	4 double -loop haptics	5	11.0	6.0	Bifocal	Refractive -diffractive	Rotationally symmetric	Apodized	0	+2.8	2.2	No	No	Bag	No
AMO	ReZoom	NXG1	Hydrophilic acrylic with PMMA haptics	3	Modified C-loop haptics	5	13.0	6.0	Bifocal	Refractive	Rotationally symmetric	Progressive	0	+3.5	3.2	No	Yes	Bag	No
	TECNIS	ZKB00	Hydrophobic acrylic	1	Modified C-loop haptics	0	13.0	6.0	Bifocal	Diffractive	Rotationally symmetric	Constant	0	+2.75	2.2	Yes	No	Bag	No
	TECNIS	ZLB00z	Hydrophobic acrylic	1	Modified C-loop haptics	0	13.0	6.0	Bifocal	Diffractive	Rotationally symmetric	Constant	0	+3.25	2.2	Yes	No	Bag	No
	TECNIS	ZMB00	Hydrophobic acrylic	1	Modified C-loop haptics	0	13.0	6.0	Bifocal	Diffractive	Rotationally symmetric	Constant	0	+4.0	2.2	No	No	Bag	Yes
	TECNIS	ZMA00	Hydrophobic acrylic	3	Modified C-loop haptics	0	13.0	6.0	Bifocal	Diffractive	Rotationally symmetric	Constant	0	+4.0	2.2	No	No	Bag	No
	TECNIS	ZM900	Silicone	3	Modified C-loop haptics	0	12.0	6.0	Bifocal	Diffractive	Rotationally symmetric	Constant	0	+4.0	2.2	No	No	Bag	No
Alcon	AcrySof IQ	ReSTOR SV25T0	Hydrophobic acrylic	1	Modified L haptics	0	13.0	6.0	Bifocal	Refractive -diffractive	Rotationally symmetric	Apodized	0	+2.5	2.2	Yes	Yes	Bag	Yes
	AcrySof IQ	ReSTOR SN6AD1	Hydrophobic acrylic	1	Modified L haptics	0	13.0	6.0	Bifocal	Refractive -diffractive	Rotationally symmetric	Apodized	0	+3.0	2.2	Yes	Yes	Bag	Yes
	AcrySof IQ	ReSTOR SN6AD3	Hydrophobic acrylic	1	Modified L haptics	0	13.0	6.0	Bifocal	Refractive -diffractive	Rotationally symmetric	Apodized	0	+4.0	2.2	Yes	Yes	Bag	No
	AcrySof IQ	PanOptix	Hydrophobic acrylic	1	Modified L haptics	0	13.0	6.0	Trifocal	Refractive	Rotationally symmetric	Constant	+2.17	+3.25	2.2	No	No up to 4.5 mm	Bag	Yes

Contd...

Table 1:Contd...

Manufacturer	IOL brand	IOL model	Material	Pieces	Haptic design	Haptic angulation (degrees)	IOL (mm)	Optic (mm)	Focallity	Optical Principle	Symmetry	Structure	Intermed add (D)	Near add (D)	Incision Size (mm)	FDA Approved	Pupil Dependence	Location	Toric version
Alsanza	Alsafit	Fourier	Hydrophobic and hydrophilic acrylic with hydrophobic surface	1	Square edge (FINS4FIT) haptics	0	11.0	6.0	Trifocal	Diffractive	Rotationally symmetric	Apodized	+1.77	+3.55	1.8	No	Yes	Bag	No
	Alsiol	3D VF	Hydrophobic and hydrophilic acrylic with hydrophobic surface		Modified loop haptics (FINS2FIT)	0	13.0	6.0	Bifocal	Diffractive	Rotationally symmetric	Not published	0	+3.75	2.0	No	Not published	Bag	No
Biotech	Eyecryl Actv	DIYHS 600 ROH	Hydrophilic acyulic with hydrophobic surface	1	Double C-loop haptics	5	12.5	6.0	Bifocal	Refractive -diffractive	Rotationally symmetric	Constant	0	+3.75	2	No	No	Bag	No
	Eyecryl Actv	DIYHS 600	Hydrophilic acrulic with hydrophobic surface	1	C-loop haptics	0	12.5	6.0	Bifocal	Diffractive	Rotationally symmetric	Constant	0	+3.0	2	No	No	Bag	Yes
Care group		AcriDIFF	Hydrophobic acrylic	1	Modified C-loop haptics	5	12.5	6.0	Bifocal	Refractive -diffractive	Rotationally symmetric	Constant	0	+3.25	2.0	No	No	Bag	Yes
	iDiff	1-R	Hydrophilic acrylic	1	Double loop haptics	0	12.5	6.0	Bifocal	Refractive -diffractive	Rotationally symmetric	Progressive	0	+3.0, +3.50, +4.0	2.0	No	Yes	Bag	Yes
	iDiff	1-P	Hydrophilic acrylic	1	Plate haptics	0	11.0	6.0	Bifocal	Refractive -diffractive	Rotationally symmetric	Progressive	0	+3.0, +3.50, +4.0	2	No	Yes	Bag	Yes
	Preziol	Multifocal Foldable IOL	Hydrophilic acrylic	1	Double C-loop haptics	0	12.5	6.0	Trifocal	Refractive	Rotationally symmetric	Progressive	+1.0	+4.0	2.8	No	No	Bag	No
	Preziol	Multifocal PMMA	PMMA	1	C-loop haptics	0	12.5	6.0	Trifocal	Refractive	Rotationally symmetric	Progressive	+1.0	+4.0	2.8	No	No	Bag	No
Carl Zeiss Meditec	AT LISA	809MP	Hydrophilic acrylic with hydrophobic surface	1	Plate haptics	0	11.0	6.0	Bifocal	Diffractive	Rotationally symmetric	Constant	0	+3.3	1.8	No	No	Bag	Yes
	AT LISA	tri 839MP	Hydrophilic acrylic with hydrophobic surface	1	Plate haptics	0	11.0	6.0	Trifocal	Diffractive	Rotationally symmetric	Zonal	+1.67	+3.3	1.8	No	No	Bag	Yes

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Table 1:Contd...

Manufacturer	IOL brand	IOL model	Material	Pieces	Haptic design	Haptic angulation (degrees)	IOL (mm)	Optic (mm)	Focallity	Optical Principle	Symmetry	Structure	Intermed add (D)	Near add (D)	Incision Size (mm)	FDA Approved	Pupil Dependence	Location	Toric version
Cristalens		Reverso	Hydrophilic acrylic	1	C-loop haptics; Piggyback lens	10	13.8	6.5	Bifocal	Diffractive	Rotationally symmetric	Not published	0	+3.0	2.0	No	Not published	Sulcus	
		Artis	Hydrophobic acrylic	1	4 double -loop haptics	5	10.8	6.0	Bifocal	Diffractive	Rotationally symmetric	Not published	0	+3.0	2.0	No	Not published	Bag	Yes
Hanita		Seelens MF	Hydrophilic acrylic	1	Modified C-loop haptics	5	13.0	6.0	Bifocal	Diffractive	Rotationally symmetric	Apodized	0	+3.0	1.8	No	Yes	Bag	No
		BunnyLens MF	Hydrophilic acrylic	1	4-point double loop haptics	5	11.0	6.0	Bifocal	Diffractive	Rotationally symmetric	Apodized	0	+3.0	1.8	No	Yes	Bag	No
Hoya Surgical Optics	AF-1 iSii	PY-60	Hydrophobic acrylic, PMMA haptics	3	Modified C-loop haptics	5	12.5	6.0	Trifocal	Refractive	Rotationally symmetric	Not published	0	+3.0	2.5	No	Yes	Bag	No
Human Optics		Diffractiva Diff-aA, Diff-aY	Hydrophilic acrylic	1	C-loop haptics	0	12.5	6.0	Bifocal	Refractive -diffractive	Rotationally symmetric	Apodized	0	+3.5	2.2	No	Yes	Bag	Yes
		Diff-sS, Diff-sAY	Silicone optic; PMMA haptic	3	C-loop haptics	0	14.0	6.0	Bifocal	Diffractive	Rotationally symmetric	Apodized	0	+3.5	2.2	No	Yes	Sulcus	Yes
		Add-On sPB, sBPY	Hydrophobic silicone optic; PMMA haptic	3	Undulating C loop haptics, piggyback IOL	10	14.0	7.0	Bifocal	Diffractive	Rotationally symmetric	Apodized	0	+3.5	2.2	No	Yes	Sulcus	No
Lenstec Inc		SBL 2	Hydrophilic acrylic	1	Plate haptics	0	11.0	5.75	Bifocal	Refractive	Rotationally asymmetric	Segmental	0	+2	Not published	no	yes	Bag	No
		SBL 3	Hydrophilic acrylic	1	Plate haptics	0	11.0	5.75	Bifocal	Refractive	Rotationally asymmetric	Segmental	0	+3	Not published	No	Yes	Bag	No
Medicontur	Bi-Flex M	677 MY	Hydrophilic and hydrophobic “hybrid copolymer”	1	Double C-loop haptics, posteriorly vaulted	0	13.0	6.0	Bifocal	Diffractive	Rotationally symmetric	Apodized	0	+3.5	1.8-2.2	No	No	Bag	Yes
MTO	Presbysmart	Crystal Evolution	Hydrophobic acrylic	1	Modified C-loop haptics	0	13.0	6.0	Bifocal	Diffractive	Rotationally symmetric	Apodized	0	+3.0, +3.5	2.2	No	Yes	Bag	Yes
	Presbysmart Plus	PSP0, PSP1, PSP2	Hydrophilic acrylic	1	Plate haptics	0	11.0	6.0	Bifocal	Diffractive	Rotationally symmetric	Not published	0	+3.0, +3.5, +4.0	1.5	No	No	Bag	No

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Table 1:Contd...

Manufacturer	IOL brand	IOL model	Material	Pieces	Haptic design	Haptic angulation (degrees)	IOL (mm)	Optic (mm)	Focallity	Optical Principle	Symmetry	Structure	Intermed add (D)	Near add (D)	Incision Size (mm)	FDA Approved	Pupil Dependence	Location	Toric version
MBI	PreciSAL	M302A, PM203A, PM302AC	Hydrophobic acrylic	1	Modified C-loop haptics	0	13.0	6.0	Bifocal	Diffractive	Rotationally symmetric	Not published	0	+3.0	2.2	No	Not published	Bag	No
Oculentis	LENTIS	Mplus MF30 (X)	Hydrophilic acrylic	1	Plate haptics	0	11.0	6.0	Bifocal	Refractive	Rotationally asymmetric	Segmental	0	+3	2.0	No	No	Bag	Yes
	LENTIS	Mplus MF20	Hydrophilic acrylic	1	Plate haptics	0	11.0	6.0	Bifocal	Refractive	Rotationally asymmetric	Segmental	0	+2	2.0	No	No	Bag	Yes
OmniLens	Revive	SQFL 600DF	Hybrid acrylic	1	Double loop haptics	5	12.5	6.0	Bifocal	Diffractive	Rotationally symmetric	Apodized	0	+3.5	2.2	No	Yes	Bag	No
PhysIOL	FineVision	Micro F	Hydrophilic acrylic	1	4 double -loop haptics	5	10.75	6.15	Trifocal	Diffractive	Rotationally symmetric	Apodized	+1.75	+3.5	1.8	No	Yes	Bag	No
	FineVision	Pod F	Hydrophilic acrylic	1	4 single -loop haptics	5	11.4	6.0	Trifocal	Diffractive	Rotationally symmetric	Apodized	+1.75	+3.5	2.0	No	Yes	Bag	YES
Rayner	M-Flex	Sulcolex Multifocal	Rayacryl, hydrophylic acrylic	1	Piggyback lens; modified undulating C-loop haptics	10	14.0	6.50	Bifocal	Refractive	Rotationally symmetric	Not published	0	+3.5	2.0	No	Yes	Sulcus	Yes
	M-Flex	Sulcolex Trifocal	Rayacryl, hydrophylic acrylic	1	Piggyback lens; modified undulating C-loop haptics	10	14.0	6.50	Trifocal	Diffractive	Rotationally symmetric	Not published	+1.75	+3.5	2.2	No	Yes	Sulcus	Yes
	M-Flex	Rayner M-Flex 580-F	Rayacryl, hydrophylic acrylic	1	Double loop haptics	0	12.0	5.75	Bifocal	Refractive	Rotationally symmetric	Zonal	0	+3, +4	1.8	No	Yes	Bag	Yes
	M-Flex	Rayner M-Flex 630-F	Rayacryl, hydrophylic acrylic	1	Double loop haptics	0	12.5	6.25	Bifocal	Refractive	Rotationally symmetric	Zonal	0	+3, +4	1.8	No	Yes	Bag	Yes
	M-Flex	RayOne	Rayacryl, hydrophylic acrylic	1	Closed loop haptics	0	12.5	6.0	Trifocal	Diffractve	Rotationally symmetric	Apodized	+1.75	+3.5	1.8	No	Yes	Bag	Yes
Soleko	Review	FIL 611 PV	Hydrophilic acrylic	1	4 double -loop haptics	5	11.0	6.0	Trifocal	Refractive	Rotationally symmetric	Not published	+2.1	+3.75	2.0	No	Not published	Bag	Yes
	Review	FIL 65 PVS	Hydrophilic acrylic	1	Double -loop haptics; pediatric lens	5	12.5	5.0	Bifocal	Refractive	Rotationally symmetric	Not published	+2.1	+3.75	3.0	No	Not published	Bag, sulcus, or scleral fixation	No

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Table 1:Contd...

Manufacturer	IOL brand	IOL model	Material	Pieces	Haptic design	Haptic angulation (degrees)	IOL (mm)	Optic (mm)	Focallity	Optical Principle	Symmetry	Structure	Intermed add (D)	Near add (D)	Incision Size (mm)	FDA Approved	Pupil Dependence	Location	Toric version
VSY biotechnology	Acriva Reviol	MF 613	Hydrophobic acrylic	1	Modified C-loop haptics	0	13.0	6.0	Bifocal	Refractive -diffractive	Rotationally symmetric	Apodized	0	+3.75	1.8	No	No	Bag	No
	Acriva Reviol	MFB 625	Hydrophobic acrylic	1	Balanced modified C-loop haptics	0	12.5	6.0	Bifocal	Refractive -diffractive	Rotationally symmetric	Apodized	0	+3.75	1.8	No	No	Bag	No
	Acriva Reviol	MFM 611	Hydrophobic acrylic	1	Plate haptics	0	11.0	6.0	Bifocal	Refractive -diffractive	Rotationally symmetric	Apodized	0	+3.75	1.8	No	No	Bag	Yes
	Acriva Reviol	Tri-ED 611	Hydrophobic acrylic	1	Plate haptics	0	11.0	6.0	Trifocal	Diffractive	Rotationally symmetric	Apodized	+1.5	+3.0		No	Yes	Bag	Yes

AMO=Abbot Medical Optic, MTO=Micro Technologie Ophtalmique, MBI=Millenium Biomedical, Inc., PMMA=Polymethylmethacrylate

refractive outcomes for both nonapodized and apodized diffractive, as well as progressive and nonprogressive refractive lenses.[15] Refractive outcome after monofocal IOL implantation is less sensitive to pupil size and IOL centration compared to multifocal IOL.[16]

Bifocal versus trifocal

Meta-analyses showed that trifocal IOLs demonstrated a small but statistically significant improvement in UDVA compared to bifocal IOL, but this difference is unlikely to represent a clinical advantage.[17-19] There was no significant difference in UNVA between bifocal and trifocal IOLs. There were no conclusive differences between bifocal and trifocal IOLs with regard to contrast sensitivity, subjective visual disturbances, spectacle independence, and patient satisfaction.[17-19] UIVA has been variably shown to be equivalent or better with trifocal compared to bifocal multifocal IOL.[17-19]

Monofocal intraocular lens versus multifocal intraocular lens

High-quality data exist in the comparison of monofocal IOL monovision with multifocal IOL and has been the subject of meta-analysis as well as a Cochrane review. Compared to monovision, patients receiving multifocal IOLs were less likely to be spectacle dependent but more likely to report glare, with no significant difference in UDVA.[20] Cochrane review and meta-analysis both demonstrated higher rates of spectacle independence with multifocal IOL compared to monovision.[20,21] However, multifocal IOL compared with monovision was not shown to provide meaningfully different UDVA, UIVA, and UNVA.[20] According to the Cochrane review, monovision demonstrated fewer symptomatic higher order aberrations compared to multifocal IOL, though with high estimate uncertainty.[21] Meta-analysis indicated that subjective visual disturbances including glare and haloes were both more common and more bothersome in patients receiving multifocal IOLs compared to monovision.[20]

Compared to multifocal IOLs, monofocal IOLs are not considered to cause reduction in contrast sensitivity, and thus may be a better choice in patients suffering from glaucoma, macular degeneration, or other diseases causing reduced contrast sensitivity.[22] There have been reports of multifocal IOL interfering with fundus visualization during vitrectomy; small-scale animal studies do not bear this out and more research is needed in this area.[23,24]

Extended Depth of Focus Intraocular Lens

EDOF IOLs have a longitudinally extended continuous focal point, rather than biphasic or triphasic peaks of best acuity as in bifocal or trifocal multifocal IOLs, and may use multifocal or pinhole optical designs to achieve this effect [Table 2].[8,9,25] The elongated focal point of

EDOF IOLs is designed to reduce overlap of near and far images as in multifocal IOLs, and theoretical studies using interferometry suggest that EDOF lenses provide better image quality at points between intermediate and near.[26]

Extended depth of focus compared to multifocal intraocular lens

Although EDOF IOLs are relatively new technology compared to multifocal IOLs, multiple comparative studies have already been performed. Of note, the currently available safety and efficacy studies of EDOF IOLs and the only available randomized controlled trial do not meet quality criteria laid out in the American Academy of Ophthalmology Task Force consensus statement on EDOF lenses.[25,27]

EDOF IOLs variably demonstrate near acuity similar to or less than diffractive IOLs but have been shown to give equal or superior results for intermediate acuity.[28,29] Haloes and glare with EDOF IOL have been variably shown to be equal to or less than with diffractive IOL.[28,29] Eye model interferometry suggests that diffractive EDOF IOLs may provide more robust presbyopic correction in the setting of defocus or large aperture (pupil).[26]

Small-aperture extended depth of focus intraocular lenses

Small-aperture IOL technology represents a unique method of creating EDOF within an IOL. The IC-8 and Xtrafocus Pinhole Implant are both small-aperture lenses have been approved for use in Europe. Small-aperture IOL has been found to reduce contrast sensitivity and allow greater tolerance of residual postoperative astigmatism compared to monofocal IOL.[30] Pupil size did not significantly affect visual acuity in patients receiving small-aperture IOL.[30] Small-aperture IOL may be a good choice in patients with cataract suffering from visual disturbances related to traumatic mydriasis.[30]

Accommodative Intraocular Lens

Accommodative IOLs are designed to respond to accommodative effort, with a change in dioptric power, and represent a diverse group of technologies that defy generalization [Table 3].[9,31] There are multiple principles, on which the current and past accommodative IOL technologies have been proposed to work, including position-changing single- or dual-optic IOLs, overlapping dual-lens varifocal IOLs, liquid-containing shape-changing IOLs, fluid interface changing IOL, and surgical techniques to fill the capsular bag with synthetic material.[31]

Accommodative IOLs should by definition demonstrate anatomically measurable changes in dioptric power in reaction to accommodative efforts.[32] Accommodation may be measured objectively with videorefractometry or streak retinoscopy, subjectively with convergence on a target or induction of defocus, or through simulation with topical pilocarpine.[32,33] Some accommodative IOL designs are predicated on accommodative ciliary muscle contraction causing IOL optic movement anteriorly, increasing dioptric power. For 1.0 mm of anterior optic movement, single-optic IOLs produce 1.0D of accommodation, whereas dual-optic IOLs produce 2.5–3.0 D of accommodation.[33,34] The amount of dioptric change in response to topical pilocarpine application as documented in the literature for each IOL is listed in Table 3. Small degrees of objectively measured accommodation with accommodative IOLs have been noted to be discordant with measured UNVA and distance-corrected near visual acuity (DCNVA), and pseudoaccommodative factors may also contribute to the near visual acuity measured in studies of accommodative IOLs.[35]

Fibrosis of the capsular bag is believed to limit the accommodative functions of accommodative IOLs. It is possible that ciliary sulcus placement may confer improved refractive outcomes, and some accommodative IOLs are designed to be placed into the ciliary sulcus. An additional advantage of accommodative IOL technology is the potential to obviate the need for patients to experience the often-difficult period of neuroadaptation that is required with multifocal IOL.[11,36] Currently, only Crystalens has been the FDA approved for sale in the United States; a much larger variety of accommodative IOLs are available worldwide. Although promising, many new accommodative IOLs are still in development. More research is needed to further develop and refine accommodative IOL technology.

Accommodative intraocular lens compared to monofocal intraocular lens

Meta-analyses have been performed comparing accommodative IOL to monofocal IOL. The majority of accommodative IOLs examined in studies included in these meta-analyses relies on single-optic forward motion within the capsular bag, and include the 1CU lens, AT-45 Crystalens, and the BioComFold IOL. Accommodating IOLs demonstrated improved DCNVA and were associated with greater anterior lens shift in response to accommodation than monofocal IOLs. However, the degree of anterior shift of accommodating IOL with pilocarpine stimulation was estimated by meta-analysis to provide <1.0 D of accommodation.[37] Spectacle independence was greater with accommodating IOLs than with monofocal IOLs.[38,39] There was no significant difference in corrected distance visual acuity and contrast sensitivity between accommodating IOLs and monofocal IOLs.[38]

Table 2: Extended Depth of Focus Intraocular Lenses

Manufacturer	IOL brand	IOL model	Material	Number of pieces	Haptic Design	Haptic Angulation (degrees)	IOL diameter (mm)	Optic diameter (mm)	Optical principle	Symmetry	Structure	Intermed add (D)	Near add (D)	Incision size (mm)	FDA approved	Location	Toric version
AMO	TECNIS	Symfony ZXR00	Hydrophobic acrylic	1	C-loop haptics	0	13.0	6.0	EDOF; diffractive	Rotationally symmetric	Achromate	+1.78	0	2.2	Yes	Bag	Yes
Acufocus incorportaed		IC-8	Biocompatible hydrogel (acrylic)	1	C-loop haptics	5	12.5	6.0	Pinhole; 3.23 central mask with 1.36 mm central aperture	Rotationally symmetric	Pinhole	0	0	3.5		Bag	No
Medicem		WIOL-CF	Methycrylic copolymer (hydrogel)	1	Bioanalog optic without haptics	n/a	10.0	8.9	Axial motion (EDOF, refractive)	Rotationally symmetric	Progressive	+1.5	+2.5	2.5	No	Posterior capsule	No
Morcher		Xtrafocus Pinhole Implant	Black hydrophobic acrylic	1	Modified C-loop haptics	14	14.0	6.0	Pinhole; 1.3 mm aperture	Rotationally symmetric	Pinhole	N/A	N/A	2.2	No; approved outside of US for treatment of irregular corneal astigmatism	Sulcus	No
Oculentis	LENTIS	Comfort LS-313 MF15	Hydrophilic acrylic	1	Plate haptics	0	11.0	6.0	EDOF refractive	Rotationally asymmetric	Segmental	+1.5	0	2.2	No		Yes
Sifi meditec		Mini well	Copolymer	1	4 fenestrated haptics	5	10.75	6.0	EDOF, refractive	Rotationally symmetric	Progressive	0	+3.00	2.2	No	Bag	Yes

AMO=Abbott Medical Optic, EDOF=Extended depth of focus, IOL=Intraocular len, N/A=Not available, FDA=Food and Drug Administration

Table 3: Accommodative Intraocular Lenses

Manufacturer	IOL brand	IOL model	Material	Number of pieces	IOL design	Haptic angulation (°)	IOL diameter (mm)	Optic diameter (mm)	Optical principle	Measured accommodation (D)	Incision size (mm)	FDA approval	Location	Toric version
AMO	Synchrony	Synchrony	Silicone	1	2 optics connected by 4 spring haptics	not published	9.8	6.0	Dual-optic motion	1	3.8	No	Bag	No
AkkoLens International	Lumina	Lumina	Acrylic	2	2 optics slide across one another, connected by spring-like haptics at lens edge	not published	Customized	Customized	Alvarez principle	2–3	2.8	No	Sulcus	No
Bausch + Lomb	Crystalens	Crystalens	Silicone optic with polymide haptics	3	Single optic with biconvex hinged plate haptics	0	12.0	5.0	Singleoptic forward motion	>0.4	2.8	Yes	Bag	Yes
Bausch + Lomb	Sarfarazi	Sarfarazi Elliptical IOL	Silicone	1	2 optics connected by 3 spring haptics	not published	9.0	5.0	Single-optic forward motion	4.0		No	Bag	No
Herzliya Pituah	NuLens	Dynacurve	PMMA -Silicone	2	4 PMMA haptics with posterior HEMA piston pressurizing silicone optic gel	not published	10.0	2.0 central piston	Axial motion	50-70	5	No	Sulcus	No
Human Optics	Akkomodative	1CU Lens	Hydrophilic acrylic	1	Single optic with 4 flexible haptics	not published	9.8	5.5	Single-optic forward motion	1.36–2.25	1.8	No	Sulcus	No
Lenstec, Inc.		Tetraflex	Hema	1	Single optic, closed loop haptics	5	11.5	5.75	Single-optic forward motion	2	2.8	No	Bag	No
Medennium	SmartIOL	SmartIOL	hydrophobic acrylic; gel at body temperature	1	Gel filling capsular bag	n/a	9.5	4.0	Accommodation		3.5		Bag	No
Morcher	BioComFold	43A, 43E	PMMA -acrylic	1	Single optic connected to 3 circumlinear broad, perforated haptics	12	10.2	5.8	Single-optic forward motion	0.7		No	Bag	No
PowerVision, Inc.		FluidVision	Hydrophobic acrylic fluid	1	Single optic and 2 C-loop haptics filled with fluid	0	10.0	6.0	Fluid movement within the IOL/Helmholtz theory	3	3.5	No	Bag	No
Soleko	Optoflex	FIL618	Acrylic	1	Single optic with 3 haptics connecting to annular ring	5	10.4	6.0	Single-optic forward motion	0.23	2.5	No	Bag	No
Tekia, Inc.		Tek-Clear	Hydrophilic acrylic	1	Single 360° full bag optic with circumferential plate haptic		11.0	5.5	Single-optic forward motion	NA	2.8	No	Bag	No

AMO=Abbott Medical Optic, IOL=Intraocular len, NA=Not available, FDA=Food and Drug Administration, PMMA=Polymethylmethacrylate

Accommodative intraocular lens compared to multifocal intraocular lens

One randomized controlled trial compared the 1CU accommodative IOL, array multifocal IOL, and Clariflex monofocal IOL.[40] In this trial, distance-corrected binocular near visual acuity was similar among accommodative and multifocal IOLs; both were superior to monofocal IOL.[40] Spectacle independence and accommodative range were superior in the multifocal IOL compared to accommodative IOL and superior in the accommodative IOL compared to monofocal IOL.[40] Rates of glare were similar among accommodative and monofocal IOL and were lower than with multifocal IOL.[40] Due to the variety of accommodative IOL technologies, the findings of this study may not be readily generalizable to all accommodative IOLs.

New Intraocular Lens Technologies

Noninvasive postoperative refractive adjustment

The RxSight Light Adjustable Lens was the FDA approved for sale in the United States in November, 2017 for patients with corneal astigmatism and without macular disease [Table 4].[41,42] This is the first IOL approved in the United States capable of noninvasive postoperative refractive adjustment. This monofocal IOL is made of material reactive to ultraviolet (UV) light delivered by the light treatment device within the first 17–21 days after surgery.[41] Refractive adjustments are made over 7–14 days postoperatively, with 3–4 light treatment sessions lasting 40–150 s each, capable of adjusting both sphere and cylinder to best fit patient preference. This treatment is the FDA approved to correct up to 2 D of residual postoperative refractive sphere and/or cylinder. Patients in clinical trials receiving this IOL gained 1 line of UDVA compared to controls.[41] Contraindications to use of the RxSight IOL include medication use that would increase sensitivity to UV light exposure and history of ocular herpes simplex virus infection.[42]

Refractive index shaping uses another kind of light to alter refraction postoperatively, that of an ultrafast femtosecond laser combined with an optical focusing device. This technology has the additional advantage of potentially creating multifocal refractive surfaces postoperatively.[43] This promising technology is currently in development by two companies: Perfect Lens in association with the University of Utah and Clerio Vision in association with the University of Rochester.[43] Unlike the RxSight lens which is currently the FDA approved for use in humans, refractive index shaping technology is still being refined in animal models.

Advantages of noninvasive postoperative refractive adjustment of an already implanted IOL include the ability to overcome unexpected refractive changes

Table 4: New Intraocular Lens Technologies

Manufacturer	IOL brand	IOL model	Material	Number of pieces	Haptic design	Haptic angulation (°)	IOL diameter (mm)	Optic diameter (mm)	Focality	Optical principle	Symmetry	Incision size (mm)	FDA approved	Pupil dependence	Location	Toric version
RxSight	LALs	RxLAL	Photoreactive UV-absorbing silicone optic; PMMA haptics	3	C-loop haptic	10	13	6	Monofocal	Light -adjustable monofocal lens	Rotationally symmetric	Not published	Yes	No	Bag	N/A
Omega		Omega gemini capsule	Prosthetic capsule with 4 haptics containing monofocal optic	multi-shelved intraocular device for lens adjustment	Intraoperative movement of IOL within shelves of device	not published	Not published	Not published	Monofocal	Operative adjustment of IOL power	Rotationally symmetric	2.4-2.75	No	No	Bag	N/A

LALs=Light-adjustable lens, RxLAL=RxSight's Light-Adjustable Lens, UV=Ultraviolet, IOL=Intraocular len, N/A=Not available, FDA=Food and Drug Administration, PMMA=Polymethylmethacrylate related to effective lens position. Refractive index shaping, though still a budding technology, may have the potential to make refractive lens adjustments or even create lens multifocality long after implantation of the original IOL.

Adjunct intraocular implant

The Omega Gemini Capsule, currently undergoing investigational use in humans in the United States, is a refractive capsule with internal shelf-like spaces designed to be implanted into the capsular bag, allowing controlled placement of an IOL into a specific location within the capsular bag [Table 4]. This in principle works to reduce unexpected postoperative shifts in effective lens position. Theoretically, the Gemini Capsule also creates the possibility of additional intracapsular IOL insertion if desired within this larger intracapsular space. In addition, an IOL placed within the shelves of the device could theoretically be moved later onto a different position to effect a refractive change as a patient ages. Although investigational implantation in humans has begun, this device is not yet in clinical trials.

Electronic intraocular lens

Still in the research fundraising phase, Swiss Advanced Vision recently announced the launch of a project to develop the Real-Time Autofocus Servo Control lens.[44] Theoretically, this lens would be designed to fully restore accommodative function using a solar energy capture system paired with a varifocal lens to allow real-time focus adjustment based on the object being viewed.[44] This technology is also advertised to potentially allow augmented reality, apps, or other interactive features to be incorporated into development of the IOL.[44] Developing this technology successfully necessitates creation of stable, biologically inert intraocular electronic circuitry and associated self-sustaining power source. This technology remains at a very early and theoretical stage in development.

Patient Selection

This is perhaps more appropriately termed patient election, as not only selecting the most desirable method of presbyopia correction but also choosing to undergo cataract surgery at all is an elective decision that must be made by the patient. Patients undergoing cataract surgery with placement of a presbyopia-correcting IOL must be motivated to be spectacle independent. In addition, patient personality must also be considered during preoperative counseling.

Multifocal IOLs by design divide light entering the eye into different focal points, causing the brain to perceive multiple images simultaneously. Processing these disparate images requires central adjustment of neural visual inputs, and this process of neuroadaptation can be time-consuming and frustrating for patients.[11] The success of neuroadaptation to multifocal IOL is dependent on individual as much as refractive factors; patients with personality traits of compulsive checking, orderliness, competence, and dutifulness have been found to be more likely to experience glare and haloes postoperatively, possibly as a result of failure of neuroadaptation.[45] Failure of neuroadaptation after multifocal IOL placement can lead to patient frustration. The most frequently reported indications for explantation of multifocal IOL are blurry vision, glare, and haloes.[46,47]

Far more common than need for IOL exchange, however, is patient dissatisfaction. In one case series, the most common cause of dissatisfaction with multifocal IOL was ametropia.[48] Postoperative ametropia is influenced by the accuracy of preoperative biometry, as well as effective lens position. In the case of multifocal IOLs, effective lens position affects the near focal distance as well.[49] Globe size also influences near focal distance outcomes; in general, the greater the distance between the cornea and the multifocal IOL, the farther the near focal distance is likely to be postoperatively.[49] Pupil size may also influence refractive outcome, and IOL selection must be undertaken carefully in patients with large pupils. Larger pupil size has been shown to improve contrast sensitivity and improve UDVA but lessen UNVA in multifocal diffractive IOL.[50] Posterior capsular opacification may also contribute to postoperative visual disturbance, and must be distinguished from higher order aberrations and associated issues with neuroadaptation related to the IOL itself. Management of patient dissatisfaction must be performed with care, and YAG capsulotomy delayed while lens exchange remains a possibility. Patient lifestyle must also be discussed, as eye trauma postoperatively may lead to lens decentration or dislocation.

Nonrefractive conditions limiting visual acuity must be evaluated and ruled out prior to pursuing presbyopia correction with IOL placement. It is necessary to exclude conditions such as amblyopia, optic neuropathy, or retinal disease that would preclude “good” vision even in an optically perfect environment. It is also necessary to exclude corneal conditions such as keratoconus, corneal scar, and other causes of irregular astigmatism that would compromise refractive outcome. In patients suffering from retinal disease, wherein detailed examination of the retina may be necessary for optimal medical and surgical management, IOL selection should be considered carefully.

Surgical Planning Considerations

Accurate preoperative biometry and lens calculations are of paramount importance in ensuring expected and desired refractive outcomes. To ensure optimal refractive outcome when using a presbyopia-correcting IOL, it is important to ensure that astigmatism has been treated to within 0.5 D. Any patients with 0.5 D or greater of regular preoperative astigmatism may benefit from toric IOL placement or limbal relaxing incisions. To this end, proper lens centration within the capsular bag is also important to refractive outcome. Although presbyopia-correcting IOLs function through a variety of optical mechanisms, all are susceptible to tilt and decentration leading to compromised optical performance. In the case of Crystalens, the only FDA approved accommodative IOL available in the United States, the risk of capsular contraction syndrome (also known as Z syndrome) must be mitigated with use of central capsulorrhexis, adequate anterior capsular coverage of plate haptics, and fastidious cortex removal.[36]

Discussion

Presbyopia-correcting IOLs comprise an area of active, ongoing development in refractive cataract surgery, and include multifocal, accommodating, and EDOF IOLs. Although several of these technologies are available in the United States, a larger array of newer IOL technology is available worldwide. Reliable achievement of expected refractive outcome and achievement of spectacle freedom postoperatively represent long-sought-after goals. Concurrent ocular pathology and patient expectations limit and complicate patient selection. In addition, the IOL selection process must be undertaken with attention to specific patient needs, and strong patient motivation for spectacle independence is an important prerequisite to selecting a presbyopia-correcting IOL. Multiple technologies exist for IOL correction of presbyopia, and in general, these technologies result in excellent UDVA and UNVA, though these technologies remain susceptible to negative effects of IOL misalignment, posterior capsular opacity, and corneal disease.[15,20,21,28,29,51] Many early presbyopia-correcting IOL technologies that were studied and compared in early large-scale trials are no longer in use, and comparing existing technologies using these prior studies as a reference point necessitates an understanding of these more historic IOLs as they relate to currently available technologies. Accommodative IOLs provide near visual acuity through a combination of accommodative and pseudoaccommodative mechanisms; this new and varied group of technologies continues to develop.[35] Effective lens position and final postoperative refractive outcome remain unpredictable surgical variables, though new technologies seek to address this.[43] IOL technology is an active area of research and development within vision science and will continue to evolve.

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Conflicts of interest

The authors declare that there are no conflicts of interests of this paper.

References

1. Pascolini D, Mariotti SP. Global estimates of visual impairment: 2010. Br J Ophthalmol 2012;96:614-8.
2. Flaxman SR, Bourne RR, Resnikoff S, Ackland P, Braithwaite T, Cicinelli MV, *et al*. Global causes of blindness and distance vision impairment 1990-2020: A systematic review and meta-analysis. Lancet Glob Health 2017;5:e1221-34.
3. Lee CM, Afshari NA. The global state of cataract blindness. Curr Opin Ophthalmol 2017;28:98-103.
4. Talley-Rostov A. Patient-centered care and refractive cataract surgery. Curr Opin Ophthalmol 2008;19:5-9.
5. Hawker MJ, Madge SN, Baddeley PA, Perry SR. Refractive expectations of patients having cataract surgery. J Cataract Refract Surg 2005;31:1970-5.
6. Keates RH, Pearce JL, Schneider RT. Clinical results of the multifocal lens. J Cataract Refract Surg 1987;13:557-60.
7. Pearce JL. Multifocal intraocular lenses. Curr Opin Ophthalmol 1996;7:2-10.
8. Alio JL, Pikkel J, editors. Multifocal Intraocular Lenses: The Art and Practice. 1st ed. Switzerland: Springer; 2014.
9. Zvorničanin J, Zvorničanin E. Premium intraocular lenses: The past, present and future. J Curr Ophthalmol 2018;30:287-96.
10. Breyer DR, Kaymak H, Ax T, Kretz FT, Auffarth GU, Hagen PR. Multifocal intraocular lenses and extended depth of focus intraocular lenses. Asia Pac J Ophthalmol (Phila) 2017;6:339-49.
11. Alio JL, Plaza-Puche AB, Férnandez-Buenaga R, Pikkel J, Maldonado M. Multifocal intraocular lenses: An overview. Surv Ophthalmol 2017;62:611-34.
12. Song IS, Yoon SY, Kim JY, Kim MJ, Tchah H. Influence of near-segment positioning in a rotationally asymmetric multifocal intraocular lens. J Refract Surg 2016;32:238-43.
13. Weghaupt H, Pieh S, Skorpik C. Comparison of pseudoaccommodation and visual quality between a diffractive and refractive multifocal intraocular lens. J Cataract Refract Surg 1998;24:663-5.
14. Xu X, Zhu MM, Zou HD. Refractive versus diffractive multifocal intraocular lenses in cataract surgery: A meta-analysis of randomized controlled trials. J Refract Surg 2014;30:634-44.
15. Soda M, Yaguchi S. Effect of decentration on the optical performance in multifocal intraocular lenses. Ophthalmologica 2012;227:197-204.
16. Hayashi K, Hayashi H, Nakao F, Hayashi F. Correlation between pupillary size and intraocular lens decentration and visual acuity of a zonal-progressive multifocal lens and a monofocal lens. Ophthalmology 2001;108:2011-7.
17. Yang JJ, Liu QP, Li JM, Qin L. Comparison of visual outcomes with implantation of trifocal versus bifocal intraocular lens after phacoemulsification: A meta-analysis. Int J Ophthalmol 2018;11:484-92.
18. Xu Z, Cao D, Chen X, Wu S, Wang X, Wu Q. Comparison of clinical performance between trifocal and bifocal intraocular lenses: A meta-analysis. PLoS One 2017;12:e0186522.
19. Shen Z, Lin Y, Zhu Y, Liu X, Yan J, Yao K. Clinical comparison of patient outcomes following implantation of trifocal or bifocal intraocular lenses: A systematic review and meta-analysis. Sci Rep 2017;7:45337.
20. de Silva SR, Evans JR, Kirthi V, Ziaei M, Leyland M. Multifocal versus monofocal intraocular lenses after cataract extraction. Cochrane Database Syst Rev 2016;12:CD003169.
21. Kelava L, Barić H, Bušić M, Čima I, Trkulja V. Monovision versus

multifocality for presbyopia: Systematic review and meta-analysis of randomized controlled trials. Adv Ther 2017;34:1815-39.

22. Cillino S, Casuccio A, Di Pace F, Morreale R, Pillitteri F, Cillino G, *et al.* One-year outcomes with new-generation multifocal intraocular lenses. Ophthalmology 2008;115:1508-16.
23. Lim JI, Kuppermann BD, Gwon A, Gruber L. Vitreoretinal surgery through multifocal intraocular lenses compared with monofocal intraocular lenses in fluid-filled and air-filled rabbit eyes. Ophthalmology 2000;107:1083-8.
24. Kawamura R, Inoue M, Shinoda K, Bissen-Miyajima H. Intraoperative findings during vitreous surgery after implantation of diffractive multifocal intraocular lens. J Cataract Refract Surg 2008;34:1048-9.
25. Akella SS, Juthani VV. Extended depth of focus intraocular lenses for presbyopia. Curr Opin Ophthalmol 2018;29:318-22.
26. Domínguez-Vicent A, Esteve-Taboada JJ, Del Águila-Carrasco AJ, Monsálvez-Romin D, Montés-Micó R. *In vitro* optical quality comparison of 2 trifocal intraocular lenses and 1 progressive multifocal intraocular lens. J Cataract Refract Surg 2016;42:138-47.
27. MacRae S, Holladay JT, Glasser A, Calogero D, Hilmantel G, Masket S, *et al.* Special report: American Academy of Ophthalmology Task Force consensus statement for extended depth of focus intraocular lenses. Ophthalmology 2017;124:139-41.
28. Savini G, Schiano-Lomoriello D, Balducci N, Barboni P. Visual performance of a new extended depth-of-focus intraocular lens compared to a distance-dominant diffractive multifocal intraocular lens. J Refract Surg 2018;34:228-35.
29. 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;34:507-14.
30. Dick HB, Piovella M, Vukich J, Vilupuru S, Lin L, Clinical Investigators. Prospective multicenter trial of a small-aperture intraocular lens in cataract surgery. J Cataract Refract Surg 2017;43:956-68.
31. Pepose JS, Burke J, Qazi M. Accommodating intraocular lenses. Asia Pac J Ophthalmol (Phila) 2017;6:350-7.
32. Glasser A. Accommodation: Mechanism and measurement. Ophthalmol Clin North Am 2006;19:1-12, v.
33. Langenbucher A, Huber S, Nguyen NX, Seitz B, Gusek-Schneider GC, Küchle M. Measurement of accommodation after implantation of an accommodating posterior chamber intraocular lens. J Cataract Refract Surg 2003;29:677-85.
34. McLeod SD. Optical principles, biomechanics, and initial clinical performance of a dual-optic accommodating intraocular lens (an American ophthalmological society thesis). Trans Am Ophthalmol Soc 2006;104:437-52.
35. Pallikaris IG, Kontadakis GA, Portaliou DM. Real and pseudoaccommodation in accommodative lenses. J Ophthalmol 2011;2011:284961.
36. Balgos MJ, Vargas V, Alió JL. Correction of presbyopia: An integrated update for the practical surgeon. Taiwan J Ophthalmol 2018;8:121-40.
37. Findl O, Leydolt C. Meta-analysis of accommodating intraocular lenses. J Cataract Refract Surg 2007;33:522-7.
38. Zhou H, Zhu C, Xu W, Zhou F. The efficacy of accommodative versus monofocal intraocular lenses for cataract patients: A systematic review and meta-analysis. Medicine (Baltimore) 2018;97:e12693.
39. Takakura A, Iyer P, Adams JR, Pepin SM. Functional assessment of accommodating intraocular lenses versus monofocal intraocular lenses in cataract surgery: Metaanalysis. J Cataract Refract Surg 2010;36:380-8.
40. Harman FE, Maling S, Kampougeris G, Langan L, Khan I, Lee N, *et al.* Comparing the 1CU accommodative, multifocal, and monofocal intraocular lenses: A randomized trial. Ophthalmology 2008;115:993-1001.e2.
41. Ford J, Werner L, Mamalis N. Adjustable intraocular lens power technology. J Cataract Refract Surg 2014;40:1205-23.
42. U.S. Food and Drug Administration. FDA Approves First Implanted Lens that can be Adjusted After Cataract Surgery to Improve Vision without Eyeglasses in Some Patients. Available from: https://www.fda.gov/NewsEvents/Newsroom/PressAnnouncements/ucm586405.htm. [Last updated on 2017 Nov 22; Last accessed on 2018 Nov 27].
43. Stuart A. Cataract Innovations. EyeNet Selections. Refractive Cataract; 2018. p. 17-21.
44. Swiss Advanced Vision Intraocular Lens. R-Tasc Project – Active Intraocular Lens. Available from: https://www.sav-iol.com/r-tasc-project-active-intraocular-lens/. [Last updated on 2018 Apr 13; Last accessed on 2018 Nov 27].
45. Mester U, Vaterrodt T, Goes F, Huetz W, Neuhann I, Schmickler S, *et al.* Impact of personality characteristics on patient satisfaction after multifocal intraocular lens implantation: Results from the "happy patient study". J Refract Surg 2014;30:674-8.
46. Mamalis N, Brubaker J, Davis D, Espandar L, Werner L. Complications of foldable intraocular lenses requiring explantation or secondary intervention–2007 survey update. J Cataract Refract Surg 2008;34:1584-91.
47. Kamiya K, Hayashi K, Shimizu K, Negishi K, Sato M, Bissen-Miyajima H, *et al.* Multifocal intraocular lens explantation: A case series of 50 eyes. Am J Ophthalmol 2014;158:215-20.e1.
48. de Vries NE, Webers CA, Touwslager WR, Bauer NJ, de Brabander J, Berendschot TT, *et al.* Dissatisfaction after implantation of multifocal intraocular lenses. J Cataract Refract Surg 2011;37:859-65.
49. Savini G, Hoffer KJ, Lombardo M, Serrao S, Schiano-Lomoriello D, Ducoli P, *et al.* Influence of the effective lens position, as predicted by axial length and keratometry, on the near add power of multifocal intraocular lenses. J Cataract Refract Surg 2016;42:44-9.
50. Alfonso JF, Fernández-Vega L, Baamonde MB, Montés-Micó R. Correlation of pupil size with visual acuity and contrast sensitivity after implantation of an apodized diffractive intraocular lens. J Cataract Refract Surg 2007;33:430-8.
51. Lyall DA, Srinivasan S, Ng J, Kerr E. Changes in corneal astigmatism among patients with visually significant cataract. Can J Ophthalmol 2014;49:297-303.