



Review

Premium intraocular lenses: The past, present and future

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Received 15 December 2017; revised 9 April 2018; accepted 25 April 2018

Available online 18 May 2018

Abstract

Purpose: To present potential benefits as well as limitations of premium intraocular lens (IOL) use, and provide insight in future of premium cataract surgery.

Methods: Bibliographic research was performed in PubMed/Medline database, and the most recently updated papers were evaluated. Keywords used were: premium intraocular lens, multifocal intraocular lens, toric intraocular lens, toric multifocal intraocular lens, accommodative intraocular lens, and the respective brand names.

Results: Multifocal IOLs provide uncorrected distance visual acuity (UDVA) of 0.03 logMAR in 82.3%–95.7% of patients and overall spectacle independence in 81%–85% of patients. Toric IOLs provide UDVA of 0.3 logMAR in 70%–95% of patients, residual astigmatism of 1 D or less is noted in 67%–88% of patients, and spectacle independence is reported in 60%–85% of patients. Toric multifocal IOLs provide UDVA of 0.3 logMAR in 92%–97% of patients, and spectacle independence is reported in 79%–90% of patients. Accommodative IOLs represent intensively developing field in ophthalmology, and the results are still variable depending on the IOL model.

Conclusions: Premium IOL technology and advanced surgical techniques have significantly improved postoperative visual outcomes. Future developments will potentiate development of new premium IOL designs that will provide spectacle independence and excellent visual outcomes after cataract surgery.

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Keywords: Multifocal IOL; Toric IOL; Accommodative IOL; Cataract surgery

Introduction

Cataract presents the leading cause of preventable blindness in the world.^{1,2} From 1990 to 2010 the number of blind and visually impaired people due to cataract decreased³; however, the total number of cataract surgeries more than tripled in the world, and the rate of cataract surgery increased in all regions, especially in Asia, with improvement of surgical techniques and a lower rate of complications.^{4,5} As the number of surgical

procedures increases every year, patient demands are becoming more challenging. Many patients expect excellent visual results and perfect vision without spectacles at both distance and proximity.

The 2016 European Society of Cataract and Refractive Surgery Clinical Survey revealed that 43% of cataract procedures are targeted for monovision.⁶ The “ideal” intraocular lens (IOL) should restore the patients' vision without complications or visual compromises at all distances.⁷ With the use of different IOLs, emmetropia can be achieved in almost all cases.^{5,7–9} Premium IOL include multifocal and accommodative IOLs meant to provide clear vision at near and distant focal points without additional spectacle correction and toric IOLs for astigmatism correction.⁵

The purpose of this review is to give an overview of the current premium IOL technology, patient selection criteria,

Source(s) of support: None.

Conflict of interest: None.

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Peer review under responsibility of the Iranian Society of Ophthalmology.

benefits and limitations of different premium IOLs, and major clinical outcomes.

Methods

Bibliographic research was performed in PubMed/Medline database for articles published between January 1, 1980 and December 1, 2017 on premium IOLs. Keywords used were: premium intraocular lens, multifocal intraocular lens, toric intraocular lens, toric multifocal intraocular lens, accommodative intraocular lens, and the respective brand names. Articles were analyzed when they reported on cataract surgery clinical trials with any type of premium IOL, their clinical results, intraoperative and postoperative complications, and relation to previous or subsequent refractive procedures. A total of 1218 articles were found. The exclusion criteria were as follows: articles not in English, articles focusing on cataract surgery safety, preoperative preparation and complications, articles focusing on cataract surgery in a special population of complex cataract, and articles in non-human subjects or human subjects under the age of 18. After exclusion, the full text of 395 articles was reviewed, and the most recently updated papers were evaluated. Data analysis and presentation focused on uncorrected distance visual acuity (UDVA) and near visual acuity. Secondary outcome parameters included were: spectacle independence for distant, intermediate, and near vision tasks, presence of photic phenomena (glare, flare, and halos), results on defocus curves, contrast sensitivity, and overall patient satisfaction. Furthermore, special emphasis was given to premium IOL history, technology, patient selection criteria, complications, and potential future developments. Technical data and characteristics for the most commonly used premium IOLs are also presented.

Results

Premium intraocular lens technology

Premium IOL technology refers to IOLs biomaterial, aspheric design, and special refractive properties. Cataract surgery is one of the oldest surgical procedures known, first documented in the fifth century BC.¹⁰ However, the first implantation of poly-methyl-methacrylate (PMMA) IOL was performed on 29th of November 1949 by Harold Ridley.¹¹ The modern era of cataract surgery started with the introduction of phacoemulsification surgery in 1967 by Charles Kelman.¹² The first IOL were made of PMMA, but different new materials are now being used for premium IOLs, including hydrophobic acrylic, hydrophilic acrylic, silicone, and PMMA biomaterials. The biomaterial used for premium IOL should ensure excellent long-term uveal biocompatibility, based on the inflammatory foreign-body reaction of the eye against the implant, and capsular biocompatibility, determined by the relationship of the IOL with residual lens epithelial cells within the capsular bag.¹³ Different IOL materials show different adhesive properties, where hydrophobic acrylic materials present highest level of adhesiveness.¹⁴ After IOL

implantation, it is also expected that anterior and posterior capsule fuse with the IOL and prevent its decentration or rotation.¹⁵

Continuous development of surgical instruments and techniques enabled reduction of corneal incision size and development of new IOL types, with enhanced postoperative refractive results.¹² The premium cataract surgery requires safe cataract surgery without significant operative or postoperative complications, as well as predictive and excellent postoperative refractive results. Traditional IOLs had a spherical optical design which could induce minor optical imperfections-higher-order aberrations. However, aspheric IOLs match more closely to the shape and optical quality of the human's natural lens and provide better vision quality. Therefore, some authors consider monofocal aspheric IOLs and yellow aspheric IOLs as premium IOLs.¹⁶ The square edges of optic in premium IOL are designed to prevent posterior capsule opacification (PCO). The size of the IOL and haptic design are also considered to be very important factors for postoperative IOL stability. The toric IOLs with a larger overall diameter have excellent early rotational stability¹⁷ while IOLs with loop haptics ensure better stability and centration than IOLs with plate haptics.¹⁸ Accommodative IOLs are still a developing field in premium IOL technology where many different designs and solutions are still discussed.¹⁹ Finally, premium IOL implies aspheric IOL with different optical characteristics (multifocal IOLs, toric IOLs, toric multifocal IOLs, and accommodative IOLs), which will be discussed in the text below.

Patient selection criteria

Before surgery it is obligatory to have a discussion with the patient in order to determine his expectations and lifestyle-related needs.⁷ Patient selection and counseling are crucial in achieving success with premium IOLs.^{7,9,20} The ideal patient is motivated to achieve spectacle independence for distance and near vision, understands the limitations of premium IOLs, and has realistic expectations.⁹ Patients should be informed about potential optical aberrations that could influence quality of vision. Some of these symptoms can later be improved through a process of neuroadaptation, but the patients must be aware of the possibility that these symptoms can permanently persist.⁸ Another important issue is a possible second surgical intervention in the sense of bilateral premium IOL implantation, which could provide significantly better visual results in both multifocal and toric IOLs.^{5,7,20}

Any preexisting ocular comorbidities that could affect the vision are relative to absolute contraindications for premium IOL implantation. Therefore, a detailed preoperative ophthalmic examination is mandatory. Ocular pathologies, such as corneal pterygia and dystrophies and especially Fuchs endothelial dystrophy, should be carefully evaluated, taking into account the progressive nature of these diseases.^{7,21} Patients with dry-eye syndrome and meibomian gland dysfunction are potentially extremely unsatisfied after cataract surgery, regardless of premium IOL type, due to tear-film

abnormalities and subjective symptoms. These conditions should be treated aggressively before the surgery.⁷

Premium IOL decentration or rotation could lead to the reduction of premium IOL efficiency, resulting in significant visual disturbances. Therefore, ocular disorders with capsular instability (pseudoexfoliative syndrome or trauma induced zonulolysis) are absolute contraindications for multifocal and relative contraindication for toric IOL implantation. Mild zonular weakness is not strict contraindication for premium IOL implantation; however, adequate preoperative and preoperative assessment is essential.⁷ In these eyes, implantation of capsular tension ring could provide stabilization of the capsular bag, and even contribute to better postoperative IOL centration.⁸

In young patients with amblyopia, functional improvement is possible with the use of premium IOL, but man should be careful because of uncertain postoperative refractive results.²² Several retinal diseases, such as retinitis pigmentosa and Statgart disease, are absolute contraindication for any premium IOL. In patients with uveitis, there is always a risk for early or late postoperative reactivation, and these patients should be avoided in premium IOL surgery. Patients with previous ocular surgeries should also be avoided in premium IOL surgery. Although not necessarily a contraindication, previous refractive ocular surgeries can induce significant amounts of higher order aberrations that may preclude the use of premium IOLs, especially multifocal IOLs.⁷

Different macular and optic nerve head diseases are associated with decreased contrast sensitivity.^{5,16} Although the multifocal IOLs can be used as an aid for magnification in eyes with age-related macular degeneration (ARMD), the surgeon must be cautious while in multifocal IOLs there is a split between near and distance foci. In some cases, this could result in further contrast sensitivity reduction and even poorer vision than with monofocal IOLs.⁷ Additionally, macular diseases such as ARMD or diabetic maculopathy can progress after any cataract surgery.²³ Care should be taken when considering for premium IOL implantation in patients with glaucoma or any optic nerve damage. Only glaucoma suspects and ocular hypertensive patients with no disk or visual field damage who have been stable for a longer period of time should be candidates for multifocal IOLs.¹⁶ Preoperative ocular coherence tomography and perimetry evaluation could rule out subtle or occult pathology while in cases of significant or progressive pathologies, multifocal IOLs are contraindicated.⁷ Furthermore, in patients with posterior eye segment changes, the visualization of macula and optic nerve will be impaired after both toric and multifocal IOL implantation, and this could result in various difficulties in later diagnostic as well as therapeutic procedures.⁷ In order to provide some spectacle independence in these patients, monofocal monovision should be considered as a viable option.²⁴

Astigmatism is an important preoperative factor, especially when considering that approximately 15%–20% of patients with cataracts have a preoperative corneal astigmatism of more than 1.25 diopter (D).^{25,26} The presence of astigmatism in eyes with multifocal IOLs compromises all distance visual

acuties, suggesting the need to correct astigmatism greater than 1.0 D.²⁷ Furthermore, posterior corneal astigmatism should also be considered in surgical planning.²⁸ Patients with irregular astigmatism are not good candidates for multifocal IOL due to questionable outcomes and refractive correction challenges.⁷ Limbal relaxing incisions or opposite clear corneal incisions can be performed during the surgery and laser refractive surgery can be used after the surgery in order to reduce astigmatism.^{29–31} On the other hand, when considering toric IOL implantation, a minimal amount of corneal astigmatism of 1.25 D should be present before the surgery.^{9,32} Regular astigmatism is most suitable for toric IOL implantation; however, irregular astigmatism in cases of keratoconus,³³ or after keratoplasty³⁴ can also be successfully treated with toric IOL implantation. For patients with regular corneal astigmatism which require spectacle independence, toric multifocal IOLs should be discussed.

Accurate IOL calculation is an important factor for excellent visual acuity, and most modern IOL formulas provide good results, even in long and short eyes.³⁵ New IOL calculation devices acquire fast, accurate, and repeatable measurements with predictable refractive results.³⁶ The procedure of cataract surgery also has several factors that may influence postoperative refractive result. The size and centration of the capsulorhexis, anterior or posterior capsule tear and in the bag IOL implantation could result in postoperative IOL decentration and reduce its function.^{7,21} The function of the premium IOL is also dependent on postoperative pupil size and position, where patients with larger pupils may have more glare and haloes, but patients with small pupils may have difficulties in intraoperative IOL centration.³⁷ Therefore, all mentioned factors should be carefully considered before opting for premium IOL implantation.

Multifocal intraocular lenses

Accommodation is the dynamic change in the refractive power of the eye to focus on objects at different distances.³⁸ With the use of monofocal IOL, refractive results for distance visual acuity are excellent; however, many patients are not satisfied with the need for additional correction for near and intermediate work. Monovision is strategy with monofocal IOLs, where one eye is implanted with IOLs dioptric power for distance vision, and the other eye is implanted with an IOL for near vision.³⁹ On the other side, multifocal IOLs should provide spectacle independence at near, intermediate, and distant vision tasks. The first concept of a truly multifocal IOL was conceived in 1983 by Hoffer,⁴⁰ and the first bifocal IOL implantation was performed by Pearce in 1986.⁴¹ Since then, many modifications and improvements in multifocal IOL concept have been made.⁴²

Regarding the optical design and used physical principles, multifocal IOLs can be classified as refractive or diffractive IOLs. Refractive multifocal IOLs on the anterior surface have ring or sector shaped optical zones with different dioptric powers and are based on geometric light rays' refraction principles. Diffractive multifocal IOLs have multiple

diffractive zones on the posterior IOL surface causing interference of optic wave-fronts. Regarding the focality (number of focal points), multifocal IOLs can be classified in bifocal, trifocal, and extended depth of focus (EDOF) multifocal IOLs. Bifocal multifocal IOLs typically incorporate a far and a near focus, and trifocal IOLs have an additional focal point for the intermediate range.³⁹ The EDOF IOLs have an extended far focus area which reaches the intermediate distance.³⁹ These IOLs present the latest generation of multifocal IOLs where Tecnis Symphony IOL (Abbott Medical Optics, Inc., Santa Ana, CA) was the first EDOF IOL approved in 2016 by the U.S. Food and Drug Administration (FDA). The EDOF technology presents a significant area for new developments in ophthalmology, and American Academy of Ophthalmology task force has provided consensus statement for EDOF IOLs. These should have an extended far focus area which reaches the intermediate distance, providing excellent intermediate vision. Depth of focus should be at least 0.5 D wider than monofocal IOL for distance visual acuity of 0.03 logMAR.⁴³

Several aspects are important for determining the clinical effectiveness of multifocal IOLs (Table 1). UDVA of 0.03 logMAR is found in 82.3%–95.7% of patients with unilateral multifocal IOL implantation.^{44,45} Furthermore, in cases of bilateral multifocal IOL implantation, it is possible to combine different types of IOLs to improve binocular visual outcomes at different distances.³⁹ This approach is called “mix and match” or “blended vision” and provides promising results especially in combination with EDOF multifocal IOLs.^{39,46} Binocular visual acuity 0.03 logMAR can be achieved in 99.9% of patients.⁴⁵ The patients with a monofocal IOL can also have both good uncorrected distance and near visual acuity resulting from favorable corneal astigmatism, favorable corneal wavefront aberrations, or myopic undercorrection in one eye, resulting in pseudophakic monovision.^{37,44} However, the results of multifocal and monofocal IOL implantation show that uncorrected near vision is significantly improved by implantation of a multifocal IOL, resulting in lower levels of spectacle dependence for near tasks without compromising distance visual acuity.^{8,37,44,45} Multifocal IOLs provided overall spectacle independence for both distant and near vision in 81.3%–84.9% of patients, compared to 7.5%–12% in monofocal IOLs. Multifocal IOLs presented better results than monofocal IOLs in UDVA, where spectacle independence for distance vision can be achieved in 93.5%–99.9% of patients with multifocal IOLs implantation, compared to 52.4%–85% of patients with monofocal IOLs implantation.⁵

Defocus curves provide another objective measure of expected vision at different distances. The new trifocal and EDOF multifocal IOLs provide better results on defocus curves and are therefore more tolerant to postoperative residual spherical equivalent, resulting in better visual quality in real life situations.³⁹ An important issue in multifocal IOLs is dependence on pupil size and resulting photic phenomena. In apodized diffractive and progressive refractive multifocal IOLs, near focus is centered, while distance foci are located at the IOL periphery. This refers to a narrow pupil size resulting from accommodation and convergence during near tasks.

Table 1
Most commonly used multifocal intraocular lenses (IOLs).

Multifocal IOL	Material	IOL design	IOL/optic diameter (mm)	Optical principle		Symmetry/Structure	Intermed/near add (D)
				Focality/Principle			
Restor AcrySof (Alcon)	Hydrophobic acrylic	Single piece loop haptics	13.0/6.0	Bifocal, Refractive-diffractive	Rotationally symmetric, Apodized	0/4	
PanOptix AcrySof (Alcon)	Hydrophobic acrylic	Single piece loop haptics	13.0/6.0	Trifocal, Refractive	Rotationally symmetric, Constant	2.17/3.25	
At Lisa ^a (Carl Zeiss Meditec)	Hydrophilic acrylic with hydrophobic surface	Single piece plate haptics	11.0/6.0	Bifocal/Trifocal Diffractive	Rotationally symmetric, Constant/Zonal	1.67/3.75–3.3	
Mplus Lentis (Oculentis)	Hydrophilic acrylic	Single piece plate haptics	11.0/6.0	Bifocal Refractive	Rotationally asymmetric, Segmental	0/2	
Comfort Lentis (Oculentis)	Hydrophilic acrylic	Single piece plate haptics	11.0/6.0	EDOF Refractive	Rotationally asymmetric, Segmental	1.5/0	
SBL 2 and 3 (LensteC INC)	Hydrophilic acrylic	Single piece plate haptics	11.0/5.75	Bifocal Refractive	Rotationally asymmetric, Segmental	0/2-3	
Mini Well (Sifi Meditec)	Hydrophilic acrylic	Single piece fenestrated haptics	10.75/6.0	EDOF, refractive	Rotationally symmetric, Progressive	0/3	
Diffractiva (Human Optics)	Hydrophilic acrylic	Single piece loop haptics	12.5/6.0	Bifocal, Refractive-diffractive	Rotationally symmetric, Apodized	0/3.5	
Symfony Tecnis (AMO)	Hydrophobic acrylic	Single piece loop haptics	13.0/6.0	EDOF, Diffractive	Rotationally symmetric, Achromate	1.78/0	
ReZoom Abbot Medical Optics	Hydrophilic acrylic	Three piece modified C loop haptics	13.0/6.0	Refractive	Zonal-progressive	0/3.5	
Tecnis ^b (Johnson & Johnson)	Hydrophobic acrylic	Single piece C loop haptics	13.0/6.0	Diffractive	Rotationally symmetric, Constant	+2.75 + 3.25 +4.0	
FineVision (PhysIOL)	Hydrophilic acrylic	Double loop haptics	10.75/6.15	Trifocal diffractive	Rotationally symmetric, Constant	+1.75/+3.5	

Add: Addition, D: Diopter, EDOF: Extended depth of focus, Intermed: Intermediate, IOL: Intraocular lens.

^a There are two types – bifocal and trifocal.

^b There are three types with near addition +2.75; +3.25 and +4.0 D.

Diffractive multifocal IOLs tend to display more stray light than refractive ones.⁴⁷ Cochener et al. found no significant difference in halos incidence between refractive and diffractive multifocal IOLs.⁴⁸ However, many control trials revealed significantly higher rate of dysphotopsias (halos and glare) in patients with multifocal IOLs compared to monofocal IOLs.^{5,39} Pooled results for contrast sensitivity measured with Pelli-Robson chart did not reveal a significant difference between monofocal and multifocal IOLs.⁴⁴ However, most of the studies have found some advantage of monofocal over multifocal IOLs in contrast sensitivity, especially under adverse conditions.^{5,49} Despite certain negative subjective phenomena, overall patient satisfaction and quality of life after multifocal IOL implantation are generally very high.^{5,8}

Toric intraocular lenses

Corneal astigmatism can be successfully treated with different modalities including: placing the corneal incision on the steep meridian, opposite clear corneal incisions, peripheral corneal relaxing incisions (up to 3 D) and with the use of toric IOL (up to 9 D).^{29,50} Toric IOLs offer the patient the opportunity to correct corneal astigmatism at the time of cataract surgery, and achieve spectacle independence for distance vision.⁹ (Table 2) The first toric IOL introduced by Shimizu and associates in 1992 was a non-foldable 3-piece PMMA IOL which required a large (5.7 mm) corneal incision.⁵¹ The first foldable single piece IOL made from silicone material was introduced in 1994 and enabled implantation through smaller corneal incision of 3.2 mm.⁵² These first toric IOLs had a high rate of postoperative rotation which resulted in high residual astigmatism and poor postoperative UDVA. Further developments led to significantly improved postoperative rotation stability and provided excellent postoperative results,

where more than 70% of all patients achieve spectacle independence.^{9,32}

Intraocular lens calculation and postoperative IOL stability as well as patient selection are the key features leading to a successful surgical procedure.³⁵ Preoperative corneal astigmatism has to be measured accurately in order to achieve effective astigmatism correction. There are different methods including manual keratometry, automated keratometry, corneal topography, and Scheimpflug imaging. It is important to note that Scheimpflug imaging can measure both anterior and posterior corneal curvature, which acts as minus lens.⁵³ The surgeon must have in mind that the posterior cornea acts as a minus lens and affects with-the-rule (WTR) and against-the-rule (ATR) astigmatism differently and that anterior corneal astigmatism continues to change towards ATR astigmatism years after the cataract surgery.^{9,26,27} Therefore, in cases of WTR astigmatism, calculated corneal astigmatism can be decreased by 0.5 D and in cases of ATR astigmatism it should be increased by 0.3 D.⁹ An additional factor is surgically induced astigmatism (SIA), which has to be incorporated in IOL power calculation. This value depends on the size of the corneal incision, location of the incision, amount or preoperative astigmatism, and patient's age.^{54–56} Individually calculated – personalized SIA based on standard astigmatism vector analysis is probably the most accurate method used for IOL calculation.^{9,57} Several calculation programs provided by the manufacturers are available for IOL calculation. These programs are easy to use, and some of them require manual data entry, but there is also a possibility for automatic data transition from refractive to surgical unit.

Generally, results of toric IOL implantation are very good with a small amount of residual astigmatism. UDVA of 0.3 logMAR is achieved in 70%–95% of patients, while more than 64% have UDVA better than 0.97 logMAR.^{32,58,59}

Table 2
Most commonly used monofocal toric intraocular lenses (IOLs).

Toric IOL	Material	IOL design	IOL diameter (mm)	Aspheric	Spherical power (D)	Cylinder power (D)	Incision size (mm)
AcrySof (Alcon)	Hydrophobic acrylic	Loop haptic	13.0	Yes	+6.0 to +30.0	+1.5 to +6.0 (0.75 steps)	2.2
AF-I toric (Hoya)	Hydrophobic acrylic with PMMA haptic tips	Loop haptic	12.5	Yes	+6.0 to +30.0	+1.5 to +3.0 (0.75 steps)	2.0
Acri.Comfort/At Torbi (Carl Zeiss Meditec)	Hydrophilic acrylic with hydrophobic surface	Plate haptic	11.0	Yes	−10.0 to +32.0	1.0 to 12.0 (0.50 steps)	< 2.0
Lentis Tplus (Oculentis)	Hydrophilic acrylic with hydrophobic surface	Loop/plate haptic	12.0/11.0	Yes	0.0 to +30.0	0.25 to 12.0 (0.75/0.01 ^a steps)	2.6
Light adjustable lens (Calhoun Vision)	Silicone with PMMA haptics	Loop haptic	13.0	Yes	+17.0 to 24.0	0.75 to 2.0	3.0
Microsil/Torica (Human optics)	Silicone with PMMA haptics	Loop haptic	11.6	No	−3.5 to +31.0	2.0 to 12.0 ^a (1.0 steps)	3.4
Morcher 89A (Morcher GmbH)	Hydrophilic acrylic	Bag in the lens	7.5	No	+10 to 30.0	0.5 to 8.0 (0.25 steps)	2.5
Staar (Staar Surgical Company)	Silicone	Plate haptic	10.8/11.2	No	9.5 to 28.5	2.0 to 3.5	2.8
T-flex (Ryner)	Hydrophilic acrylic	Loop haptic	12.0/12.5	Yes	−10.0 to +35.0	1.0 to 11.0 (0.25 steps)	<2.0
Tecnis toric (Abbot Medical Optics)	Hydrophobic acrylic	Loop haptic	13.0	Yes	5.0 to 34.0	1.0 to 4.0 (0.5 steps)	2.2

IOL: Intraocular lens, PMMA: Poly-methyl-methacrylate.

^a Customized.

Residual astigmatism of 1 D or less is noted in 67%–88% of cases, while astigmatism of 0.5 D or less can be found in 67% of all cases.⁵⁸ Spectacle independence for far vision after toric IOL implantation is reported between 60% and 85% of patients with unilateral toric implantation.^{58,60,61} Average post-operative toric IOL rotation is less than 5°, and toric IOLs provide better results than monofocal IOL or limbal relaxing incisions.³² Subjective quality of vision can be further improved by bilateral toric IOL implantation.⁶¹

Toric multifocal intraocular lenses

As discussed before, multifocal toric IOLs offer the opportunity for spectacle independence for distance, intermediate, and near vision regardless to the corneal astigmatism (Table 3). However in patients with toric multifocal IOLs, surgeons have to face even more potential error sources, including the rotational stability and the correct estimation of corneal astigmatism.⁶² Therefore, preoperative assessment is even more crucial for excellent refractive outcomes.

Results of multifocal toric IOLs implantation present UDVA of 0.3 logMAR in 92%–97% and 0.97 logMAR in 71% of patients.^{62–65} Residual astigmatism less than 1 D is noted in more than 89% of patients.^{62,65,66} Complete freedom of spectacles can be achieved in 79%–90% of patients.^{62,66} The incidence of moderate to severe photic phenomena is limited, and the rate of satisfaction with the procedure is 84%.⁶² These results confirm that the combination of multifocal and toric correction in an IOL is well tolerated and can achieve excellent final visual outcome.^{9,62}

Accommodative intraocular lenses

Accommodative IOL are designated to produce a dynamic increase in the dioptric power of the eye with accommodative effort.^{20,24} The Crystalens developed by Cumming in 1989 was the first FDA approved accommodative IOL in 2003.⁶⁷ Several accommodating IOL design strategies have been proposed including: position-changing single or dual optic IOLs, shape changing IOLs, refractive index modulating accommodative IOL designs, and lens filling surgical

techniques.²⁰ Positional pseudo-accommodative IOLs mechanism of action is based on changing the axial position of monofocal IOL in relation with the cornea, and 1 mm of movement is equivalent of 2 D of power change.¹⁹ Similarly, shape changing or fluid flow based IOLs change their optic power based on fluid flow resultant to capsular pressure increase due to accommodative effort.²⁰ However, accommodative properties of accommodative IOLs can be very dependent on the flexibility of the capsular bag.^{68,69} Therefore, it is widely discussed whether IOL should be placed in the capsular bag or in the ciliary sulcus.⁷⁰ All commercially available accommodative IOLs can be custom-made considering spherical power and are highly dependent to the amount of ocular astigmatism.^{19,20,24}

Clinical results of different accommodative IOLs regarding distance visual acuity and contrast sensitivity are similar to monofocal IOLs.²⁴ However, the near vision and accommodation extent are significantly different between the models¹⁹ (Table 4). Approximately 40%–70% of patients still use reading glasses after accommodative IOL implantation, and more than half of the patients complain on halos and glares.^{19,20} Defocus curves provide a great variety of results, while this group of lenses consists of IOLs with significantly different designs. Overall, patient satisfaction is also variable (10%–80%)¹⁹ and might be a consequent to the lack of standardization in present studies.⁷² Therefore, more studies are required to evaluate clinical outcomes of present accommodative IOLs.^{19,20,72}

Premium intraocular lens complications

Phacoemulsification is considered to be a safe and effective operative method, where 94.3% of all patients have good postoperative visual acuity.⁷³ Incidence of intraoperative complications, namely posterior capsule rupture, is relatively small (1.92%), and higher-risk cases can be predicted, thus better informing the consent process and allowing surgeons to take appropriate precautions.⁷⁴ During follow-up, many post-operative changes and complications that could influence the efficacy of premium IOLs can be noted. The most commonly cited reasons for patient dissatisfaction after premium IOL

Table 3
Most commonly used toric multifocal intraocular lenses (IOLs).

Toric IOL	Material	IOL design	IOL diameter (mm)	Multifocal technology	Near addition (D)	Spherical power (D)	Cylinder power (D)	Incision size (mm)
Acrysof IQ Restor toric (Alcon)	Hydrophobic acrylic	Loop	13.0	Diffraction + refractive	+3.0	+6.0 to 34.0	1.0 to 3.0 (0.5–0.75 steps)	2.2
Acri.Lisa Toric (Carl Zeiss meditec)	Hydrophilic acrylic with hydrophobic surface	Plate	11.0	Diffraction	+3.75	–10.0 to +32.0	1.0 to 12.0 (0.5 steps)	<2.0
M-flex T (Rayner)	Hydrophilic acrylic with hydrophobic surface	Loop	12.0/12.5	Refractive	+3.0 to +4.0	+14.0 to 32.0	+1.5 to +6.0 (0.5 steps)	<2.0
Lentis Mplus toric (Oculentis)	Hydrophilic acrylic with hydrophobic surface	Plate	11.0	Sector shaped refractive segment	+3.0	0.0 to +36.0	+0.25 to +12.0 (0.75 steps custom)	2.6
Tecnis ZMT (Abbott)	Hydrophobic acrylic	Loop	13.0	Diffraction	+4.0	+5.0 to 34.0	+1.5 to +4.0 (0.5 steps)	2.2

D: Diopter, IOL: Intraocular lens.

Table 4
Most commonly used accommodative intraocular lenses (IOLs).

Accomm IOL	Material	IOL design	IOL/optic diameter (mm)	Mechanism of action	Location	Measured accomm (D)	Incision size (mm)
Crystalens (Bausch Lomb)	Silicone	Biconvex hinged plate haptic	11.5–12.0/5	Single optic forward motion	Capsular bag	>0.4	2.8
ICU Lens (Human optics)	Hydrophilic acrylic	4 flexible haptics	9.8/5.5	Single optic forward motion	Capsular bag	1.36–2.25	3.0
Tetraflex (Lenstec Inc)	Hema	Closed loop haptics	11.5/5.75	Single optic forward motion	Capsular bag	2	2.8
Synchrony (Abbott)	Silicone	2 optics with 4 spring haptics	9.8/5.5–6.0	Dual optic IOL	Capsular bag	1	3.8
Lumina (AkkoLens Int)	Acrylic	Elastic loop with a spring function	Customized	Alvarez principle	Ciliary sulcus	2–3	2.8
NuLens (Herzliya Pituah)	PMMA-Silicone	4 PMMA haptics with posterior piston	2.0 central piston 10.0 overall	Axial motion	Ciliary sulcus	50–70 ^a	9.0
Tek-Clear (Tekia, Inc.)	Hydrophilic acrylic	360° full bag haptic	10.0–11.0/5.5	Single optic forward motion	Capsular bag	NA	3.0
WIOL-CI (Medicem)	Methacrylic copolymer	Bioanalog product	10.0/8.6–8.9	Axial motion	Capsular bag	NA	2.8
FluidVision (PowerVis)	Hydrophobic acrylic fluid	2Fluid filled haptics	10.0/6.0	Fluid movement within the IOL	Capsular bag	3	3.5

Accomm: Accommodation, D: Diopter, IOL: Intraocular lens, NA: Not available, PMMA: Poly-methyl-methacrylate.

^a Theoretical range of accommodation for the NuLens is 50–70 D, but the clinical data presented range of accommodation up to 10 D.^{20,71}

implantation are blurred vision due to ametropia, dry-eye-syndrome, PCO, photic phenomena due to IOL decentration, retained lens fragment, and large pupil.^{21,37} The rates of PCO following cataract surgery are estimated to be 12% at year 1, 21% at year 3, and 28% at 5 years after surgery.⁷⁵ Incidence of other relatively common postoperative complications is broadly different based on definitions used for pseudophakic cystoid macular edema between 1.17% and 4.2%, posterior vitreous detachment between 7.8% and 73.3%, retinal detachment 0.7%, and IOL dislocation 0.28%.^{76–78}

In patients with toric IOLs, misalignment is an important factor for adequate visual function. It can be the result of inaccurate alignment during the surgery or postoperative IOL rotation.⁹ Toric IOLs show very stable IOL position with insignificant postoperative rotation.⁷⁹ However, long-term corneal astigmatism changes towards ATR astigmatism must be taken in account.²⁶ Also, ocular trauma after cataract surgery can be an important factor for IOL stability.⁸⁰

Residual refractive error is the most common cause of unsatisfactory visual acuity resulting in suboptimal visual outcomes in nearly 64% of patients.³⁷ Preoperative causes include misestimation of postoperative IOL position and preoperative axial length measurement, inadequate selection of the IOL power, limitations of the calculation formulas (especially in extreme ametropia), and the lack of precision in the manufacturing of IOLs.^{21,81,82} Premium IOLs provide significant improvement in distance and near visual acuity over standard monofocal IOL; however, relatively common adverse effects put some question on validity of their use. Furthermore, multifocal IOLs constitute 6%–31% of all IOLs reported to be explanted, and the most common reason for explantation of these lenses was due to optical aberrations such as glare, halos, and dysphotopsias.⁸³ This is still an individual question that depends on patients' motivation.⁴⁴ Proper management of the

unhappy premium IOL patient requires time, patience, and familiarity with different medical and surgical options and techniques.⁷

Future developments

Since the introduction of premium IOLs, many improvements in IOL design, material, and surgical technique have been made. Additional refinements in surgical technique, IOL calculation, IOL design, and alignment may further improve postoperative visual results.⁹ Laser-assisted cataract surgery has been showing significantly improved results since its introduction in 2009. The use of a computer-controlled femtosecond laser-assisted cataract surgery (FLACS) may improve consistency and precision of the corneal incisions as well as anterior capsulotomy.^{84,85} Currently, FLACS procedures may offer small and relatively inconsistent refractive advantages over conventional phacoemulsification and clear corneal incisions.⁸⁵ However, the possibility for creating precise and predictive corneal relaxing incisions during or after the cataract surgery is also one of the main advantages of FLACS. The dominant error in IOL power calculations is the determination of the effective lens position. Therefore, improvement in surgical precision through FLACS and FLACS-derived improvement in IOL power calculations might furthermore improve refractive postoperative results.⁸⁵ Additionally, improvement in IOL design and perhaps the appearance of effective accommodative IOLs that would be widely commercially available will be the endpoint of clinical use of monofocal as well as premium IOLs available today.¹⁹ These further developments in cataract surgery could provide excellent postoperative refractive results for almost all patients at all working distances, regardless to their preoperative refractive state.

Discussion

The topic of premium IOLs has attracted the attention of a number of ophthalmic surgeons and clinicians as well as the ophthalmic industry.⁸ Premium IOLs have been shown to result in UDVA of 0.3 logMAR - 20/40 or better in almost all properly selected patients. Different premium IOLs provide different qualities as well as their own limitations. Multifocal IOLs are associated with higher rates of spectacle independence than monofocal IOLs, but are more frequently associated with dysphotopsias and decreased contrast sensitivity.⁵ Toric and multifocal toric IOL implantation in patients with cataract and corneal astigmatism result in excellent distance and near visual acuity and result in spectacle independence.⁹ However, IOL misalignment and age-related corneal changes might compromise long-term results and efficacy of these IOLs.^{9,25,26} On the other hand, there is still some controversy regarding the results of accommodative IOLs, but emerging models of accommodative IOLs should solve this controversy by providing sustainable and reliable evidence based results.⁸

Cataract surgery provides generally a high rate of patient satisfaction. However, there is no universally accepted and standard validated measure of patient satisfaction after cataract surgery.⁸ With current premium IOLs, appropriately selected patients can achieve spectacle independence and good visual outcomes at both near and distance.⁷ However, premium IOLs show significant sensitivity to minor ocular aberrations; therefore, adequate preoperative clinical evaluation is crucial to postoperative success. Nevertheless, despite careful selection and screening, some patients will experience unsatisfactory outcomes. Adequate management of both satisfied and unsatisfied patients will improve the benefit of current premium IOLs.⁷ In the future, development of more precise and standardized measurements will provide better and more predictable postoperative visual results. Long-term prevention of PCO is defectively an issue that also needs to be addressed with the IOL implantation in the ciliary sulcus or some other strategy for in the bag implantation. Future developments will defectively potentiate development of new premium IOL designs that will provide spectacle independence and excellent visual outcomes after cataract surgery at all distances.

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