

What is in a posterior chamber intraocular lens? A review of the basic properties, materials and designs

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Abstract

There is a vast array of posterior chamber intraocular lenses on the market with different materials and designs. Materials used for an intraocular lens can be divided into hydrophobic and hydrophilic. Hydrophobic materials include polymethyl methacrylate, foldable hydrophobic acrylic and silicone. Hydrophilic materials include hydrophilic acrylic and collamer. The intraocular lens can be three-piece or one-piece, open-loop or plate-haptic. Different designs are also adopted to reduce posterior capsular opacification, reduce optical aberrations, filter light of unwanted or harmful wavelengths, and correct astigmatism and presbyopia. In this review, we summarize the existing literature on common materials and designs used for currently available posterior chamber intraocular lenses. It is hoped that this will facilitate surgeons in choosing an appropriate intraocular lens for their patients.

Key words: Biocompatible materials; Lens implantation, intraocular; Posterior eye segment; Prosthesis design

Introduction

With the current vast number of choices of posterior chamber intraocular lenses (IOL) on the market, it is important to understand the different properties of IOL materials and designs in order to choose a suitable IOL. From a

patient's point of view, an ideal IOL should provide good visual acuity over a wide range of distances with minimal aberration and glare, and long-term stability and safety at a low cost. Surgeons will have additional considerations that include ease of handling and insertion through a small incision, intraocular biocompatibility, minimal bacterial and fungal adherence, availability of diopter range and incremental range, low posterior capsule opacification (PCO) rate, filtration of unwanted wavelengths and minimization of various optical aberrations.

Materials of intraocular lens

IOL materials are hydrophobic or hydrophilic based on the angle at which a water droplet falls on the surface of the lens (**Table 1¹⁻¹¹**). Hydrophobic materials repel water and result in a greater contact angle with water. Hydrophilic materials combine or attract water and result in a more acute contact angle with water. Amon¹² classified the biocompatibility of IOL as uveal or capsular. Uveal biocompatibility refers to the reaction of uveal tissue to the IOL, the body's natural immunologic response to a foreign object involving macrophages and foreign body giant cells. Capsular biocompatibility refers to the reaction of the residual lens epithelial cells (LEC) to the IOL. Proliferation of LEC on the anterior and posterior capsules leads to capsular opacities. Excessive proliferation is defined as low capsular biocompatibility.

Hydrophobic IOL materials include polymethyl methacrylate (PMMA), foldable hydrophobic acrylic and silicone, while hydrophilic materials include hydrophilic

Table 1. Commonly used materials for intraocular lens.¹⁻¹¹

Material	Hydrophilicity	Refractive index (RI)	Flexibility	Potential for small incision size	Capsular biocompatibility*
Polymethyl methacrylate	Inherently hydrophobic but can undergo heparin surface modification to become hydrophilic	1.49	+	+	+
Foldable hydrophobic acrylic	Hydrophobic	1.44-1.55	++	+++	++++
Hydrophilic acrylic	Hydrophilic	1.43 (newer materials developed with different RI)	+++	++++	++
Silicone	Hydrophobic	1.41-1.46	+++	++	+++
Collamer	Hydrophilic	1.45	+++	+++	+++

* Based on individual studies but no significant differences shown in meta-analysis.¹⁻¹¹

acrylic and collamer. PMMA, foldable hydrophobic acrylic, hydrophilic acrylic and collamer are all acrylic polymers and copolymers. The mechanical properties of acrylic polymers change with temperature. At low temperatures, they are rigid and glass-like, and at high temperatures they are soft and fluid-like. This change occurs within a narrow temperature range, with the mid-point known as the ‘glass transition temperature’, and is important for foldable IOL. The glass transition temperature of PMMA is between 118.8°C and 113.5°C, so that at room temperature, PMMA is rigid and glass-like. The glass transition temperature of foldable hydrophobic acrylic IOL is typically below room temperature between 15.5°C and 14°C so they are foldable for insertion into the eye where it unfolds into its original shape.¹³ Silicone is between -91.7°C and -119.6°C but has rubber-like characteristics at room temperature and unfolds rapidly within the eye. Hydrophilic acrylic lenses have values between 111.2°C and 95.9°C in a dehydrated state but become soft and elastic when hydrated.

Polymethyl methacrylate

PMMA is a rigid, transparent material with a refractive index of 1.49. It is inherently hydrophobic but can undergo heparin surface modification (HSM) to become hydrophilic.

Advantages of PMMA include its high uveal biocompatibility, allowance for surface modification, good centration and resistance to tilt due to its rigidity, low cost and rare occurrence of glistenings.¹³ Nonetheless, it requires a large incision due to its rigidity and is also brittle, has a higher risk of injuring the corneal endothelium, and is less tolerant to Nd:YAG laser damage during laser capsulotomy procedures.¹⁴ It is currently used in extracapsular cataract extraction, scleral-fixated and anterior chamber IOL.

Foldable hydrophobic acrylic

Foldable hydrophobic acrylic is a series of copolymers of acrylate and methacrylate derived from rigid PMMA. The first foldable hydrophobic acrylic IOL was introduced onto the market in 1993 as the AcrySof three-piece IOL (Alcon Laboratories, Fort Worth [TX], USA). This material has become the most popular IOL material worldwide. Foldable

hydrophobic acrylic IOL come in three-piece or one-piece designs, and have a refractive index of 1.44 to 1.55. Their advantages include lower PCO rate,¹⁻³ ease of manipulation as they are less slippery, a high refractive index that allows for a thinner optic, good resistance to Nd:YAG laser^{14,15} and a relatively low risk of silicone oil condensation.¹⁶ The minimum incision size for hydrophobic acrylic IOL is 2.2 mm, between that of silicone and hydrophilic acrylic IOL. Hydrophobic acrylic IOL can be associated with more glare and photopsia postoperatively than other materials due to their low anterior curvature and higher refractive index,^{17,18} and more common occurrence of glistening.¹³ ‘Glistening’ describes the phenomenon in which aqueous humor penetrates the IOL and water microvacuoles develop within the IOL optic giving an appearance of small bright crystals (**Figure 1**). In the majority of cases, this does not result in any significant visual alterations, although it can be associated with nighttime glare and reduced contrast sensitivity.¹⁹ To overcome this drawback, new materials have been introduced that are pre-hydrated to equilibrium water content so that they will not accept any further water. An example is the enVista MX60 (Bausch and Lomb Incorporated, Rochester [NY], USA) [**Figure 2**].²⁰ There

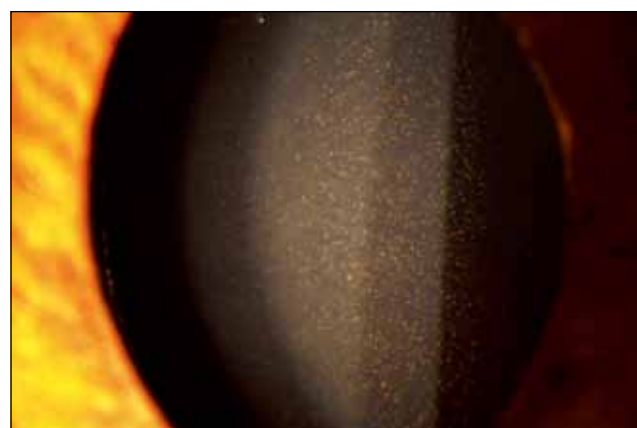


Figure 1. Slit-lamp photo of glistening of acrylic intraocular lens.

have been two case reports of significant surface deposits during implantation of a foldable hydrophobic acrylic IOL, leading to explantation.^{21,22} The deposits were noted immediately after the IOL was injected into the anterior chamber and could not be entirely removed by irrigation and aspiration. Subsequent analysis of the explanted IOL suggested that the deposits might have resulted from crystallization of the ophthalmic viscoelastic device used during loading of the IOL into the cartridges. The authors proposed that the ophthalmic viscoelastic device could have dried out and precipitated on the IOL while still inside the cartridge, and the adhesive nature of hydrophobic acrylic may make removal of precipitates from the IOL surface difficult.²¹

Hydrophilic acrylic

Hydrophilic acrylic was introduced as a material for IOL in the 1980s. It comprises a mixture of hydroxyethylmethacrylate (HEMA) and hydrophilic acrylic monomer and is a heterogeneous group with highly variable water content. In hydrophilic acrylic IOL, the lower the water content, the greater the refractive index and resistance. The typical refractive index is 1.43 but newer materials have been developed that have different refractive indices, such as Akreos Adapt Advanced Optic (AO) lens (Bausch and Lomb Incorporated, Rochester [NY], USA), a copolymer of HEMA with incorporation of PMMA with a refractive index of 1.46. Two key advantages of hydrophilic acrylic IOL are their superior mechanical properties and theoretically higher uveal biocompatibility. They are softer and more compressible than hydrophobic acrylic, and hence can be implanted through a smaller incision. They are also easier to handle with a low tendency for scratch marks, and a lower risk of capsular bag damage during implantation. They are also more resistant to Nd:YAG laser¹⁵ and have lower damage potential when touching the corneal endothelium. Hydrophilic acrylic IOL, however, have a higher PCO rate¹⁻³ that can be due to adherence of water molecules to the IOL surface, and lower adhesiveness to the capsule. The softer nature also makes them weaker with lower resistance to capsular bag contraction, and may

not be ideal if high contraction force is anticipated, as in some eyes with pseudoexfoliation syndrome. Postoperative optic opacification of hydrophilic acrylic IOL, now rarely reported, was a significant complication leading to large-scale explantation of a hydrogel lens, Hydroview IOL (Bausch and Lomb Incorporated, Rochester [NY], USA). First used in 1999, the problems usually occurred months to years later, and appeared as fine opaque granules deposited on the surface and within the IOL optic.^{22,23} It was probably caused by a deposition of calcium and phosphate salts but the exact mechanism was unknown. It was observed to be more common in patients with systemic conditions such as diabetes mellitus and hypertension, and may have been due to the associated metabolic imbalance, altered fluid dynamics of the aqueous or breakdown of the blood-aqueous barrier.^{22,23} Although optic opacification is now rare with newer materials of hydrophilic acrylic IOL, there have been some case reports of opacification of Akreos Adapt AO IOL; all of which occurred in patients with diabetes.²⁴⁻²⁶ Silicone oil adherence to hydrophilic acrylic had been reported to be lower than that for PMMA, hydrophobic acrylic and silicone IOL.^{16,27} Nonetheless, calcification in hydrophilic acrylic IOL in eyes with silicone oil has been reported.²⁸ There has also been one case report of blue discoloration of a hydrophilic acrylic IOL (Acqua; Mediphacos, Belo Horizonte, Brazil) by intraoperative trypan blue. Acqua IOL was manufactured from hydrophilic acrylic material with a high water content (73.5%) and was implanted in a dry state. Hydration therefore depended on fluids in the capsular bag and hence could possibly absorb the dye during intraocular expansion.²⁹ Laboratory testing with various IOL materials showed that only hydrophilic acrylic IOL could significantly absorb commonly used capsular dyes.³⁰

Silicone

Silicone IOL are made from polymers of silicone and oxygen. They are hydrophobic with a refractive index of 1.41 to 1.46. Although silicone IOL are mechanically flexible, they are less commonly used nowadays due to their various drawbacks, including the lower refractive index and hence thicker optics and larger incision size, difficulty in manipulation because they are slippery when wet, abrupt opening inside the anterior chamber, problem of glistenings, more posterior and anterior capsular opacification compared with acrylic IOL,^{1,2} low resistance to damage by Nd:YAG laser¹⁴ and importantly, irreversible adherence of silicone droplets.^{16,27,31} They are thus relatively contraindicated in patients at risk of vitreoretinal surgery such as those with diabetic retinopathy or highly myopia. They were also suspected to favor bacterial adhesion.³² Although rare, there have been case reports of calcifications of silicone IOL in asteroid hyalosis, and tan-brown discoloration in older models.²² Despite its drawbacks, the silicone light-adjustable lens is an exciting technology that allows spherical and even cylindrical power to be adjusted postoperatively. They contain silicone macromers that contain an ultraviolet light-activated photoinitiator. Curvature of the lens can be changed by activation of the photoreactive components by a special ultraviolet light causing polymerization in the area

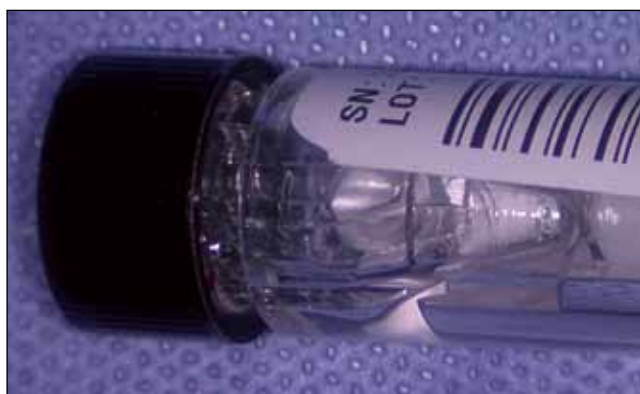


Figure 2. Prehydrated hydrophobic acrylic intraocular lens enVista MX60 (Bausch and Lomb Incorporated, Rochester [NY] USA).

of exposure so that unpolymerized macromers will diffuse into the area of treatment down a diffusion gradient. It is currently in phase 3 studies in the USA.³³

Collamer

Collamer derives its name from the combination of collagen and polymer. It is made of a HEMA copolymer combined with a hydrophilic porcine collagen (<0.1%). It is hydrophilic and has a refractive index of 1.45. It is used exclusively in making STAAR phakic and aphakic lenses (STAAR Surgical, Monrovia [CA], USA), including the Visian Implantable Collamer lens (STAAR Surgical, Monrovia [CA], USA). Similar to hydrophilic acrylic, they have a high uveal biocompatibility^{34,35} and are easy to implant due to their softness and gentle unfolding. Theoretically, the collagen in collamer attracts fibronectin that forms a layer around the IOL to promote adhesion between the collagen-containing capsule and the LEC as well as between the LEC and the IOL to prevent PCO.³⁵

Material properties of intraocular lens

Capsular biocompatibility

In terms of PCO rates, the IOL material is less important than the sharp edge design. Various studies have reported higher PCO rates with hydrophilic acrylic IOL.^{1,3-5} A European study of 1525 patients reported PCO and Nd:YAG capsulotomy rates to be the highest in hydrophilic acrylic, followed by PMMA, silicone and hydrophobic acrylic in decreasing order.¹ A Cochrane review of interventions for preventing PCO, however, showed no significant differences in PCO rates between different IOL optic materials.² The sandwich theory, which described the prevention of further epithelial ingrowth by a sealed sandwich structure formed by a monolayer of LEC bonding to both the posterior capsule and a bioactive IOL material, could theoretically account for the difference in PCO rates across different IOL materials. Foldable hydrophobic acrylic has a higher degree of bioadhesiveness, that is, the degree of adhesion of the capsule to the IOL surface, than hydrophilic acrylic, PMMA and silicone,⁶⁻⁹ hence the low PCO rate. Studies that compared electron microscope images of hydrophobic and hydrophilic acrylic IOL also reported a sharper edge with hydrophobic acrylic IOL that may be related to the manufacturing process.^{10,11}

Uveal biocompatibility

Hydrophilic materials are theoretically more uveal biocompatible than hydrophobic materials,³⁶⁻³⁸ because IOL will be surrounded by aqueous humor intraocularly, and the reduced electrostatic forces and cellular adhesion may prevent attraction of inflammatory cells and adherence of fibroblasts to the surface of IOL.^{39,40} A recent Cochrane review evaluating IOL in uveitic eyes, however, did not report any significant differences in uveal biocompatibility between hydrophobic and hydrophilic IOL.^{41,42} Heparin coating can theoretically reduce postoperative inflammation due to the anticoagulant and anti-inflammatory effects of heparin. Nonetheless, results of whether HSM PMMA

gave better outcomes in uveitic eyes compared with non-modified PMMA were conflicting, with some reporting better outcomes with HSM PMMA IOL and some reporting no statistically significant differences.^{40,41,43} A randomized clinical trial comparing postoperative inflammation and capsular reaction in eyes that received heparin-coated foldable acrylic IOL and same IOL without heparin coating also failed to demonstrate any significant differences between the two groups.⁴⁴ Nevertheless, the number of reviews is limited. Studies have involved small numbers and there is insufficient evidence to show that any IOL material is superior to another for uveitic eyes that have to undergo cataract surgery.

Bacterial adherence

Hydrophilic-hydrophobic interactions may influence bacterial adhesion to IOL and may be associated with infection risk. Since postoperative endophthalmitis is rare, an extremely large sample size would be required to draw reliable conclusions. Epidemiological studies of the contribution of IOL materials have reported conflicting results. Some studies reported that polypropylene haptics and unmodified PMMA were associated with higher postoperative endophthalmitis rates.^{45,46} Experimental studies reported that hydrophobic IOL such as silicone or acrylic hydrophobic IOL were more permissive to bacterial adhesion and growth than hydrophilic IOL.³² A multicenter study by the European Society of Cataract & Refractive Surgeons also identified silicone IOL as one of the risk factors associated with postoperative endophthalmitis.⁴⁷ The results of these studies should be interpreted with caution because bacterial adhesion and endophthalmitis are complicated processes affected by many other factors such as operating technique, and ocular and systemic risk factors.

Designs of intraocular lenses

Posterior chamber IOL can have many different designs. Common designs include three-piece or one-piece, and open-loop or plate-haptic.

Three-piece intraocular lenses

Three-piece IOL consist of an optic and two open 'C-loop' haptics that are made of different materials, with the haptics inserted into two holes at the optic border. The optic can be made of PMMA, silicone or acrylic, while the haptic can be made of PMMA, polyvinylidene fluoride or polyamide. Polypropylene has previously been used for haptics but has since been abandoned because of postoperative degradation. Disadvantages of a three-piece IOL include risk of damage to the haptics when injected with an injector and hence possible need for a bigger incision than one-piece IOL, and possible brusque movements of the haptics during unfolding that may cause posterior capsular rupture. Advantages include their suitability for sulcus implantation in cases with posterior capsular rupture and good capsular fixation.

One-piece intraocular lenses

One-piece IOL are produced from a single step with optics

and haptics made of the same material. Some newer models also incorporate additional materials into the haptics, such as PMMA to the tip of the haptic in Hoya iSert 251 (HOYA Surgical Optics, Tokyo, Japan) [Figure 3]. One-piece IOL are more resistant to damage when implanted with injectors, and facilitate a smaller incision compared with three-piece IOL. One-piece IOL are not for sulcus placement due to the risk of iris chafing by the thick, square haptics.⁴⁵ There have been concerns about the broad haptic-optic transition on one-piece IOL leading to interrupted square edge and increased risk of PCO, but studies have not shown any differences in PCO rates between one-piece and multi-piece IOL.⁴⁶⁻⁴⁸ Most new designs, e.g. Tecnis (Abbott Medical Optics Inc, Santa Ana [CA], USA), incorporate a 360° square edge (Figure 4). One-piece IOL can have open loop or plate haptics. One-piece IOL with plate haptics were used in one of the first foldable IOL (Figure 5). They permit a small incision and can be rotated clockwise and counterclockwise, an advantage especially for toric IOL. A major drawback is the incomplete fusion between anterior and posterior capsules along the plate-haptic axis and consequent lack of capsule bending at the optic edge theoretically allowing LEC



Figure 3. Incorporation of polymethyl methacrylate to the tip of the haptic in Hoya iSert 251 (HOYA Surgical Optics, Tokyo, Japan).



Figure 4. 360° square edge of Tecnis intraocular lens (Abbott Medical Optics Inc, Santa Ana [CA], USA).

migration and increasing the risk of PCO. Dislocation into the vitreous cavity by capsular bag contraction following posterior capsulotomy is also possible.⁴⁸ Plate-style haptics are now used in some hydrophilic IOL, collamer and silicone IOL, sometimes combined with small loop-like haptics to improve centration. Some designs use a combination of plate-style and open-loop haptics to allow adaptation to different bag sizes and reduce PCO rates. Other designs have multiple haptics to improve stability and centration in the capsular bag, such as Akreos Adapt AO IOL (Bausch and Lomb Incorporated) [Figure 6].

Designs to reduce posterior capsular opacification

PCO is the most frequent complication of cataract surgery, affecting 20% to 40% of patients postoperatively.^{49,50} Although it can be easily treated by Nd:YAG laser capsulotomy, this will incur additional costs and the laser procedure has potential complications such as intraocular pressure spike, intraocular inflammation, IOL pitting and damage, cystoid macular edema, retinal break and retinal

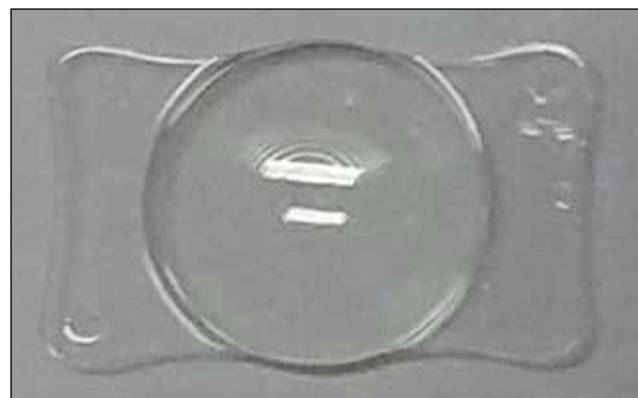


Figure 5. A multifocal intraocular lens with plate-haptic design.



Figure 6. Four-haptic design of Akreos Adapt Advanced Optic intraocular lens (Bausch and Lomb Incorporated, Rochester [NY], USA).

Table 2. Intraocular lens designs to minimize posterior capsule opacification.

Design	Rationale
Square optic edge	Prevent lens epithelial cells migration, pressure atrophy, contact inhibition
Biconvex-shaped optic	Increase contact surface with posterior capsule
Forward angulation / offset of haptics	Maintain backward position of the optic to improve contact with posterior capsule

detachment. Therefore, many efforts have been made to prevent the formation of PCO (**Table 2**). The fundamental concept is to minimize space between the posterior surface of the IOL and the posterior capsule. Measures to reduce PCO include IOL factors and surgical factors. Surgical factors are of paramount importance, such as thorough cortical clean-up, appropriately sized continuous curvilinear capsulorhexis so that the rhexis edge overlaps the IOL optic edge entirely, in-the-bag IOL implantation and a good centration of IOL.

Optic edge

In terms of IOL design, the most important modification is the square optic edge. The square optic edge design, initially a result of the manufacturing process rather than a deliberate attempt to decrease PCO, was clearly demonstrated in several studies including a Cochrane review to significantly lower PCO rate and Nd:YAG rate compared with round-edged IOL of any material.² The possible mechanisms include prevention of LEC migration, pressure atrophy and contact inhibition. The advantage is reduced if the capsulorhexis is larger than the optic as the pressure exerted by the IOL on PCO will be reduced. Nonetheless a square edge, especially when combined with a high refractive index, was reported to cause persistent 'edge-glare phenomenon'.⁵¹⁻⁵³ The optic disturbance was due to the sharp edge causing light rays that are refracted from the periphery of the IOL to be more intense on the peripheral retina, while a round edge disperses light rays over a larger surface area of the retina and hence causes less glare. Some designs to minimize the glare include a rounded anterior edge such as Sensar AR40 (Allergan Surgical, Irvine [CA], USA), and frosted edge in Tecnis ZCB00 (Abbott Medical Optics Inc, Santa Ana [CA], USA).

Optic shape

Currently, most optics of IOL are biconvex with different relationships between the anterior and posterior curvatures. The biconvex design aims to increase the contact surface with the posterior capsule to decrease the risk of PCO. The geometry of the IOL changes significantly with IOL power and some low- or minus-power lenses have a meniscus design. Optic shape directly affects the position of the principal planes of the IOL. With the change in shape of the optic as the IOL power changes from plus to minus, the principal planes shift from one side to the other and hence the A constant, which characterizes the position of the principal planes of the IOL and the effective lens position after implantation, is different for plus- or minus-power IOL.

Angulation of haptics

Some haptics have a forward angulation of 5° to 10° and this can theoretically maintain the backward position of the optic to lower the risk of iris contact and allow a greater contact area with the posterior capsule. Studies, however, have failed to demonstrate a significant reduction in IOL-posterior capsule distance or superior PCO-inhibiting effect.⁵⁴

Reduction of aberrations

Optical aberrations are classified into different orders based on the complexity of the shape of the wavefront emerging through the pupil. With a spherical lens, the rays that pass through the periphery do not converge on the same point as those that pass through the center. With an aspheric lens, the radius of the curvature of the lens from the center to the periphery is modified so that all rays focus on a single point. Spherical aberration decreases contrast, especially at large pupils, causing problems with activities such as night driving. The shape of the cornea itself causes a positive spherical aberration. When the crystalline lens is healthy, transparent and flexible, it naturally causes negative aberration and compensates for the positive corneal spherical aberration. With aging, the spherical aberration caused by the lens becomes increasingly positive and the total aberration of the optical system increases. An aspheric IOL has a modified prolate anterior surface. They are either neutral concerning spherical aberration, which means they induce zero spherical aberration, and do not add any spherical aberration to the eye, e.g. SofPort Advanced Optics (Bausch and Lomb Incorporated, Rochester [NY], USA); or they induce negative spherical aberration that neutralizes the positive corneal spherical aberration. Designs with a highly prolate anterior surface induce a more negative spherical aberration in an attempt to negate all the corneal spherical aberration and produce a pseudophakic eye with zero spherical aberration, e.g. Tecnis ZCB00 (Abbott Medical Optics, Santa Ana [CA], USA), which induces -0.27 microns of spherical aberration. Some designs take into account that a low positive spherical aberration has been reported to be associated with 'supernormal' visual abilities,⁵⁵ and aim to leave the pseudophakic eye with a low positive spherical aberration. An example is Acrysof IQ (Alcon Laboratories, Fort Worth [TX], USA) that induces -0.20 microns of spherical aberration.

In reality, the impact of addressing asphericity is very small relative to correcting spherical error and astigmatism, hence patients are unlikely to notice any difference if they are not emmetropic. Unless the patient has a postoperative

refractive error of plano or chooses to wear spectacles to correct the residual refractive error, they are unlikely to appreciate the difference of an aspheric IOL. Studies using aspheric IOL have not shown any difference in best-corrected visual acuity, although some have shown better contrast sensitivity^{56,57} and performance in nighttime driving simulation testing.⁵⁸

Centration is another concern with some aspheric IOL. Spherical IOL do not create major problems if they decenter as they add positive spherical aberration to the optical system. IOL that are neutral concerning spherical aberration have the same power in the center and at every point out to the periphery, so if they decenter they too will not confound any existing aberrations. Nonetheless IOL that induce negative spherical aberration will induce a significant amount of coma even with low degrees of decentration or tilting. If there are concerns about IOL decentration after implantation, such as in cases of posterior capsular rupture, a standard IOL or IOL with neutral spherical aberration will be preferable.

Previous corneal surgeries may also affect the corneal spherical aberration. Patients with previous hyperopic LASIK will have a negative corneal spherical aberration while patients with previous myopic LASIK will have a more positive corneal spherical aberration. The former will benefit from a traditional spherical IOL and the latter from a negative spherical aberration IOL.

Filtering unwanted wavelengths

All IOL now filter ultraviolet light by incorporating ultraviolet light-absorbing materials because ultraviolet light is potentially toxic to the retina. Blue light-filtering IOL have also added yellow chromophore to block blue wavelength light (400-460 nm). In-vitro and animal studies have suggested that blocking short-wavelength light might be beneficial in protecting the retina.^{59,60} A small study reported reduced geographical atrophy in eyes with blue light-filtering IOL,⁶¹ but epidemiological studies regarding blue light-filtering IOL and age-related macular degeneration are still lacking. Some studies suggested a reduction in glare with blue light-filtering IOL.⁶²⁻⁶⁴ With regard to visual performance of clear or blue light-filtering IOL, the majority of studies have reported similar visual acuity, photopic, scotopic and color vision performance.^{65,66} The incidence of cyanopsia, where the patient notices a blue tinge to vision after surgery, has been reported to be less during the initial postoperative period in patients with blue light-filtering IOL, but no difference was reported in clear or blue light-filtering IOL at 3 months, suggesting adaptation over time.⁶⁷ A minority of patients reported subjective differences in color and contrast perception when one eye had a blue light-filtering IOL and the other eye had a clear IOL.⁶⁸ It may be safer to match the other eye if one is operated on with or without blue light filter. Studies have also shown no significant differences between clear and blue-light filtering IOL in terms of effect on circadian rhythm and sleep-wake cycle,^{69,70} effect on optical coherence tomography imaging⁷¹

and visual field testing,⁷² or intraoperative impediment and postoperative outcomes in combined cataract and vitreoretinal surgery.⁷³

Correcting astigmatism

Toric IOL effectively neutralize pre-existing corneal astigmatism in cataract patients at the time of surgery. Systematic reviews have shown promising clinical outcomes in toric IOL implantation, in particular superior uncorrected distance visual acuity, greater spectacle independence and lower amounts of residual astigmatism compared with non-toric IOL.^{74,75} Currently, a wide range of models of toric IOL is commercially available, for example, AcrySof IQ Toric and AcrySof IQ ReSTOR multifocal toric (Alcon Laboratories, Fort Worth [TX], USA), Tecnis Toric (Abbott Medical Optics, Inc, Santa Ana [CA], USA), Trulign Toric (Bausch and Lomb Incorporated, Rochester [NY], USA), Staar Toric (Staar Surgical, Monrovia [CA], USA), etc. Toric IOL are made of hydrophobic acrylic, hydrophilic acrylic, silicone or PMMA biomaterials.⁷⁶

Accurate axis placement of the toric IOL is key to achieving good refractive outcome as 3.3% of toric correction is lost for every degree off the desired axis.⁷⁷ Being 30° off axis will result in complete loss of astigmatic correction. Toric IOL have a marking on the optic to guide alignment with the steep axis of the cornea, and should be marked with the patient seated as the eye may undergo cyclotorsion when the patient assumes a supine position.⁷⁸ Innovative intraoperative wavefront aberrometry, iris fingerprinting, limbal registration and other surgical guidance systems can improve the accuracy of alignment. Rotational stability, especially when the capsular bag contracts and the anterior and posterior capsular surfaces fuse, is also crucial for toric IOL efficiency. Toric IOL design and materials have been shown to play a role. A randomized controlled trial demonstrated that one-piece acrylic toric IOL had better rotational stability than a plate-haptic silicone toric IOL.⁷⁹

Correcting presbyopia

Accommodative function of the natural lens is lost after cataract surgery and as a consequence, spectacles will be required for near vision if standard monofocal IOL are used. Presbyopia-correcting IOL have been developed to overcome this loss of accommodation. Multifocal IOL and accommodating IOL are in this armamentarium.

Multifocal intraocular lenses

Multifocal IOL are designed to overcome a lack of accommodation by dividing the incoming light onto two or more focal points for distance, near or intermediate vision. The two broad categories of multifocal IOL are diffractive and refractive lenses. Diffractive multifocal IOL utilize diffractive zones across the lens surface to create different focal points.⁸⁰ They can be further enhanced via apodization to allow for progressive variation across the zones,⁸¹ in order to improve efficiency and optimize quality of vision achieved. Refractive multifocal IOL work by incorporating different powers into circular refractive zones.⁸⁰ AcrySof

ReSTOR IOL (Alcon Laboratories, Fort Worth [TX], USA) has a central diffractive portion, while ReZoom (Abbott Medical Optics, Inc, Santa Ana [CA], USA) and Tecnis Symphony multifocal lenses (Abbott Medical Optics, Inc, Santa Ana [CA], USA) are examples of multifocal IOL based on refractive principles.

A meta-analysis of peer-reviewed publications demonstrated the effectiveness of multifocal IOL, with a mean spectacle independence of 80.1%.⁸² Nonetheless visual complaints after surgery are more common in multifocal than monofocal IOL.⁸³ These visual problems include reduced contrast sensitivity and the photic phenomenon of halo and glare, resulting in suboptimal visual quality. With neuroadaptation, the effect of optical aberrations may lessen after a period of adjustment,⁸⁴ but the neural adaptability to multifocality varies greatly among individuals.

Accommodating intraocular lenses

To overcome the lack of accommodation in pseudophakic patients and to avoid optical side-effects of multifocal IOL, accommodating IOL have been developed. These are dynamic devices designed to effect a change in optical power in response to contraction of ciliary muscles and axial movement of the optic, thereby restituting the accommodative function of the eye.⁸⁵ There are two main types of accommodating IOL: single optic and dual optic.

The single-optic lens was developed first and several models are available, such as Crystalens (Bausch and Lomb Incorporated, Rochester [NY], USA), 1CU (HumanOptics AG, Erlange, Germany), Tetraflex (Lenstec Inc, Florida, USA) and Tek-Clear (Tekia, California, USA). Nonetheless

the limitation of single-optic accommodating IOL stems from the small amplitude of excursion⁸⁶ that translates into insufficient accommodative power generation to yield adequate and consistent near vision. The accommodative response in eyes implanted with accommodative IOL has been reported to be lower than 0.4D using laser ray tracing aberrometry.⁸⁷ Dual-optic accommodating IOL are different in that there are two coaxial optics. They comprise a high-plus power anterior optic coupled to a compensatory minus posterior optic by a spring system. This maximizes the production of accommodative power by design.⁸⁸ Synchrony dual-optic accommodating IOL (Visiogen, Inc, Irvine [CA], USA) and Sarfarazi Elliptical Accommodating IOL (Bausch and Lomb, Rochester [NY], USA) are examples.

Accommodating IOL appear to be an up-and-coming alternative to monofocal or multifocal IOL in achieving spectacle independence, but at present they are still in the nascent stage of development. More large-scale studies of their efficacy and safety are necessary to support a transformation of practice.

Conclusion

With a sound knowledge of the various properties of an IOL, surgeons can discuss with patients the different options, choose the best IOL for their patients, especially in special conditions such as chronic uveitis, and optimize the postoperative visual outcome.

Declaration

All authors have disclosed no conflicts of interest.

References

1. Auffarth GU, Brezin A, Caporossi A, et al. Comparison of Nd: YAG capsulotomy rates following phacoemulsification with implantation of PMMA, silicone, or acrylic intra-ocular lenses in four European countries. *Ophthalmic Epidemiol*. 2004;11:319-29.
2. Findl O, Buehl W, Bauer P, Sycha T. Interventions for preventing posterior capsule opacification. *Cochrane Database Syst Rev*. 2010;(2):CD003738.
3. Li Y, Wang J, Chen Z, Tang X. Effect of hydrophobic acrylic versus hydrophilic acrylic intraocular lens on posterior capsule opacification: meta-analysis. *PLoS One*. 2013;8:e77864.
4. Hollick EJ, Spalton DJ, Ursell PG, Meacock WR, Barman SA, Boyce JF. Posterior capsular opacification with hydrogel, polymethylmethacrylate, and silicone intraocular lenses: two-year results of a randomized prospective trial. *Am J Ophthalmol*. 2000;129:577-84.
5. Hayashi K, Hayashi H. Posterior capsule opacification after implantation of a hydrogel intraocular lens. *Br J Ophthalmol*. 2004;88:182-5.
6. Linnola RJ. Sandwich theory: bioactivity-based explanation for posterior capsule opacification. *J Cataract Refract Surg*. 1997;23:1539-42.
7. Linnola RJ, Sund M, Ylönen R, Pihlajaniemi T. Adhesion of soluble fibronectin, vitronectin, and collagen type IV to intraocular lens materials. *J Cataract Refract Surg*. 2003;29:146-52.
8. Yan Q, Perdue N, Sage EH. Differential responses of human lens epithelial cells to intraocular lenses in vitro: hydrophobic acrylic versus PMMA or silicone discs. *Graefes Arch Clin Exp Ophthalmol*. 2005;243:1253-62.
9. Linnola RJ, Salonen JJ, Happonen RP. Intraocular lens bioactivity tested using rabbit corneal tissue cultures. *J Cataract Refract Surg*. 1999;25:1480-5.
10. Iwase T, Nishi Y, Oveson BC, Jo YJ. Hydrophobic versus double-square-edged hydrophilic foldable acrylic intraocular lens: effect on posterior capsule opacification. *J Cataract Refract Surg*. 2011;37:1060-8.
11. Hancox J, Spalton D, Cleary G, et al. Fellow-eye comparison of posterior capsule opacification with AcrySof SN60AT and AF-1 YA-60BB blue-blocking intraocular lenses. *J Cataract Refract Surg*. 2008;34:1489-94.
12. Amon M. Biocompatibility of intraocular lenses. *J Cataract Refract Surg*. 2001;27:178-9.
13. Ronbeck M, Behndig A, Taube M, Koivula A, Kugelberg M. Comparison of glistenings in intraocular lenses with three

- different materials: 12-year follow-up. *Acta Ophthalmol.* 2013;91:66-70.
14. Newland TJ, McDermott ML, Elliott D, et al. Experimental neodymium:YAG laser damage to acrylic, poly(methyl methacrylate), and silicone intraocular lens materials. *J Cataract Refract Surg.* 1999;25:72-6.
 15. Trinavarat A, Atchaneeyasakul L, Udompunturak S. Neodymium:YAG laser damage threshold of foldable intraocular lenses. *J Cataract Refract Surg.* 2001;27:775-80.
 16. McLoone E, Mahon G, Archer D, Best R. Silicone oil-intraocular lens interaction: which lens to use? *Br J Ophthalmol.* 2001;85:543-5.
 17. Bournas P, Drazinos S, Kanellas D, Arvanitis M, Vaikoussis E. Dysphotopsia after cataract surgery: comparison of four different intraocular lenses. *Ophthalmologica.* 2007;221:378-83.
 18. Radford SW, Carlsson AM, Barrett GD. Comparison of pseudophakic dysphotopsia with Akreos Adapt and SN60-AT intraocular lenses. *J Cataract Refract Surg.* 2007;33:88-93.
 19. Henriksen BS, Kinard K, Olson RJ. Effect of intraocular lens glistening size on visual quality. *J Cataract Refract Surg.* 2015;41:1190-8.
 20. Heiner P, Ligabue E, Fan A, Lam D. Safety and effectiveness of a single-piece hydrophobic acrylic intraocular lens (enVista®) - results of a European and Asian-Pacific study. *Clin Ophthalmol.* 2014;8:629-35.
 21. Hickman MS, Werner L, Mamalis N, et al. Intraoperative explantation of two single-piece hydrophobic acrylic intraocular lenses due to surface deposits. *Eye (Lond).* 2006;20:1054-60.
 22. Werner L. Causes of intraocular lens opacification or discoloration. *J Cataract Refract Surg.* 2007;33:713-26.
 23. Yu AK, Ng AS. Complications and clinical outcomes of intraocular lens exchange in patients with calcified hydrogel lenses. *J Cataract Refract Surg.* 2002;28:1217-22.
 24. Forlini M, Orabona GD, Bratu AI, Rossini P, Cavallini GM, Forlini C. Akreos Adapt AO intraocular lens opacification: a case report. *Case Rep Ophthalmol.* 2013;4:151-4.
 25. Lee CE, Kim YC, Chang SD. Opacification of the optic of an Akreos Adapt intraocular lens. *Korean J Ophthalmol.* 2010;24:371-3.
 26. Park DI, Ha SW, Park SB, Lew H. Hydrophilic acrylic intraocular lens optic opacification in a diabetic patient. *Jpn J Ophthalmol.* 2011;55:595-9.
 27. Arthur SN, Peng Q, Apple DJ, et al. Effect of heparin surface modification in reducing silicone oil adherence to various intraocular lenses. *J Cataract Refract Surg.* 2001;27:1662-9.
 28. Rosca C, Munteanu M, Tamasoi I, et al. Calcification of hydrophilic acrylic intraocular lens in eyes with silicone oil tamponade — an interventional case series report. *Acta Ophthalmol.* 2016;94:625-7.
 29. Werner L, Apple DJ, Crema AS, et al. Permanent blue discoloration of a hydrogel intraocular lens by intraoperative trypan blue. *J Cataract Refract Surg.* 2002;28:1279-86.
 30. Ozbek Z, Saatci AO, Durak I, Gunenc U, Ergin MH, Cingil G. Staining of intraocular lenses with various dyes: a study of digital image analysis. *Ophthalmologica.* 2004;218:243-7.
 31. Apple DJ, Isaacs RT, Kent DG, et al. Silicone oil adhesion to intraocular lenses: an experimental study comparing various biomaterials. *J Cataract Refract Surg.* 1997;23:536-44.
 32. Baillif S, Ecochard R, Casoli E, Frenay J, Burillon C, Kodjikian L. Adherence and kinetics of biofilm formation of *Staphylococcus epidermidis* to different types of intraocular lenses under dynamic flow conditions. *J Cataract Refract Surg.* 2008;34:153-8.
 33. Mamalis N. Adjustable intraocular lens technology. *J Cataract Refract Surg.* 2014;40:1059-60.
 34. Sanders DR; ICL in Treatment of Myopia Study Group. Postoperative inflammation after implantation of the implantable contact lens. *Ophthalmology.* 2003;110:2335-41.
 35. Schild G, Amon M, Abela-Formanek C, Schauersberger J, Bartl G, Kruger A. Uveal and capsular biocompatibility of a single-piece, sharp-edged hydrophilic acrylic intraocular lens with collagen (Collamer): 1-year results. *J Cataract Refract Surg.* 2004;30:1254-8.
 36. Alió JL, Chipont E, BenEzra D, et al. Comparative performance of intraocular lenses in eyes with cataract and uveitis. *J Cataract Refract Surg.* 2002;28:2096-108.
 37. Abela-Formanek C, Amon M, Kahraman G, Schauersberger J, Dunavoelgyi R. Biocompatibility of hydrophilic acrylic, hydrophobic acrylic, and silicone intraocular lenses in eyes with uveitis having cataract surgery: Long-term follow-up. *J Cataract Refract Surg.* 2011;37:104-12.
 38. Abela-Formanek C, Amon M, Schild G, Schauersberger J, Heinze G, Kruger A. Uveal and capsular biocompatibility of hydrophilic acrylic, hydrophobic acrylic, and silicone intraocular lenses. *J Cataract Refract Surg.* 2002;28:50-61.
 39. Kang S, Kim MJ, Park SH, Joo CK. Comparison of clinical results between heparin surface modified hydrophilic acrylic and hydrophobic acrylic intraocular lens. *Eur J Ophthalmol.* 2008;18:377-83.
 40. Tabbara KF, Al-Kaff AS, Al-Rajhi AA, et al. Heparin surface-modified intraocular lenses in patients with inactive uveitis or diabetes. *Ophthalmology.* 1998;105:843-5.
 41. Leung TG, Lindsley K, Kuo IC. Types of intraocular lenses for cataract surgery in eyes with uveitis. *Cochrane database Syst Rev.* 2014;(3):CD007284.
 42. Roesel M, Heinz C, Heimes B, Koch JM, Heiligenhaus A. Uveal and capsular biocompatibility of two foldable acrylic intraocular lenses in patients with endogenous uveitis — a prospective randomized study. *Graefes Arch Clin Exp Ophthalmol.* 2008;246:1609-15.
 43. Perry LJ, Papaliodis GN. Selection of intraocular lenses in patients with uveitis. *Int Ophthalmol Clin.* 2010;50:61-70.
 44. Maedel S, Hirschall N, Chen YA, Findl O. Effect of heparin coating of a foldable intraocular lens on inflammation and capsular bag performance after cataract surgery. *J Cat Refract Surg.* 2013;39:1810-7.
 45. Raskin EM, Speaker MG, McCormick SA, Wong D, Menikoff JA, Pelton-Henrion K. Influence of haptic materials on the adherence of staphylococci to intraocular lenses. *Arch Ophthalmol.* 1993;111:250-3.
 46. Kodjikian L, Beby F, Rabilloud M, et al. Influence of intraocular lens material on the development of acute endophthalmitis after cataract surgery? *Eye (Lond).* 2008;22:184-93.
 47. Endophthalmitis Study Group, European Society of Cataract & Refractive Surgeons. Prophylaxis of postoperative endophthalmitis following cataract surgery: results of the ESCRS multicenter study and identification of risk factors. *J Cataract Refract Surg.* 2007;33:978-88.
 48. Petersen AM, Bluth LL, Champion M. Delayed posterior dislocation of silicone plate-haptic lenses after neodymium:YAG capsulotomy. *J Cataract Refract Surg.* 2000;26:1827-9.
 49. Lundqvist B, Mönestam E. Ten-year longitudinal visual function and Nd: YAG laser capsulotomy rates in patients less than 65 years at cataract surgery. *Am J Ophthalmol.* 2010;149:238-44.e1.
 50. Wormstone IM, Wang L, Liu CS. Posterior capsule opacification. *Exp Eye Res.* 2009;88:257-69.
 51. Davison JA. Positive and negative dysphotopsia in patients with acrylic intraocular lenses. *J Cataract Refract Surg.* 2000;26:1346-55.

52. Franchini A, Gallarati BZ, Vaccari E. Computerized analysis of the effects of intraocular lens edge design on the quality of vision in pseudophakic patients. *J Cataract Refract Surg.* 2003;29:342-7.
53. Holladay JT, Lang A, Portney V. Analysis of edge glare phenomena in intraocular lens edge designs. *J Cataract Refract Surg.* 1999;25:748-52.
54. Schmidbauer JM, Escobar-Gomez M, Apple DJ, Peng Q, Arthur SN, Vargas LG. Effect of haptic angulation on posterior capsule opacification in modern foldable lenses with a square, truncated optic edge. *J Cataract Refract Surg.* 2002;28:1251-5.
55. Grimson JM, Schallhorn SC, Kaupp SE. Contrast sensitivity: establishing normative data for use in screening prospective naval pilots. *Aviat Space Environ Med.* 2002;73:28-35.
56. Sandoval HP, Fernández de Castro LE, Vroman DT, Solomon KD. Comparison of visual outcomes, photopic contrast sensitivity, wavefront analysis, and patient satisfaction following cataract extraction and IOL implantation: aspheric vs spherical acrylic lenses. *Eye (Lond).* 2008;22:1469-75.
57. Caporossi A, Martone G, Casprini F, Rapisarda L. Prospective randomized study of clinical performance of 3 aspheric and 2 spherical intraocular lenses in 250 eyes. *J Refract Surg.* 2007;23:639-48.
58. McBride DK, Matson W. Assessing the significance of optically produced reduction in braking response time: possible impacts on automotive safety among the elderly. Potomac Institute for Policy Studies Report; 2003.
59. Nilsson SE, Textorius O, Andersson BE, Swenson B. Clear PMMA versus yellow intraocular lens material. An electrophysiologic study on pigmented rabbits regarding "the blue light hazard". *Prog Clin Biol Res.* 1989;314:539-53.
60. Sparrow JR, Miller AS, Zhou J. Blue light-absorbing intraocular lens and retinal pigment epithelium protection in vitro. *J Cataract Refract Surg.* 2004;30:873-8.
61. Pipis A, Toulou E, Pillunat LE, Augustin AJ. Effect of the blue filter intraocular lens on the progression of geographic atrophy. *Eur J Ophthalmol.* 2015;25:128-33.
62. Gray R, Hill W, Neuman B, Houtman D, Potvin R. Effects of a blue light-filtering intraocular lens on driving safety in glare conditions. *J Cataract Refract Surg.* 2012;38:816-22.
63. Gray R, Perkins SA, Suryakumar R, Neuman B, Maxwell WA. Reduced effect of glare disability on driving performance in patients with blue light-filtering intraocular lenses. *J Cataract Refract Surg.* 2011;37:38-44.
64. Hammond BR. Attenuating photostress and glare disability in pseudophakic patients through the addition of a short-wave absorbing filter. *J Ophthalmol.* 2015;2015:607635.
65. Downes SM. Ultraviolet or blue-filtering intraocular lenses: what is the evidence? *Eye (Lond).* 2016;30:215-21.
66. Cuthbertson FM, Peirson SN, Wulff K, Foster RG, Downes SM. Blue light-filtering intraocular lenses: review of potential benefits and side effects. *J Cataract Refract Surg.* 2009;35:1281-97.
67. Hayashi K, Hayashi H. Visual function in patients with yellow tinted intraocular lenses compared with vision in patients with non-tinted intraocular lenses. *Br J Ophthalmol.* 2006;90:1019-23.
68. Schweitzer C, Colin J. Patient-reported difference following implantation of a blue light-filtering aspheric intraocular lens and a UV-filtering aspheric intraocular lens. *Case Rep Ophthalmol.* 2013;4:248-51.
69. Landers JA, Tamblyn D, Perriam D. Effect of a blue-light-blocking intraocular lens on the quality of sleep. *J Cataract Refract Surg.* 2009;35:83-8.
70. Schmoll C, Khan A, Aspinall P, et al. New light for old eyes: comparing melanopsin-mediated non-visual benefits of blue-light and UV-blocking intraocular lenses. *Br J Ophthalmol.* 2014;98:124-8.
71. Kim JH, Kim NR, Lee ES, Rho S, Kang SY, Kim CY. Influence of blue light-filtering intraocular lenses on retinal nerve fiber layer measurements by spectral-domain optical coherence tomography. *Curr Eye Res.* 2011;36:937-42.
72. Kim JY, Choi JA, Na KS, Joo CK. The effect of yellow tinted intraocular lenses on the result of frequency doubling perimetry after cataract surgery. *Korean J Ophthalmol.* 2011;25:29-32.
73. Falkner-Radler CI, Benesch T, Binder S. Blue light-filter intraocular lenses in vitrectomy combined with cataract surgery: results of a randomized controlled clinical trial. *Am J Ophthalmol.* 2008;145:499-503.
74. Kessel L, Andresen J, Tendal B, Erngaard D, Flesner P, Hjortdal J. Toric intraocular lenses in the correction of astigmatism during cataract surgery: a systematic review and meta-analysis. *Ophthalmology.* 2016;123:275-86.
75. Agresta B, Knorz MC, Donatti C, Jackson D. Visual acuity improvements after implantation of toric intraocular lenses in cataract patients with astigmatism: a systematic review. *BMC Ophthalmol.* 2012;12:41.
76. Visser N, Bauer NJ, Nuijts RM. Toric intraocular lenses: historical overview, patient selection, IOL calculation, surgical techniques, clinical outcomes, and complications. *J Cataract Refract Surg.* 2013;39:624-37.
77. Vicković IP, Loncar VL, Mandić Z, Iveković R, Herman JS, Sesar A. Toric intraocular lens implantation for astigmatism correction in cataract surgery. *Acta Clin Croat.* 2012;51:293-7.
78. Prickett AL, Bui K, Hallak J, et al. Cyclotorsional and non-cyclotorsional components of eye rotation observed from sitting to supine position. *Br J Ophthalmol.* 2015;99:49-53.
79. Chua WH, Yuen LH, Chua J, Teh G, Hill WE. Matched comparison of rotational stability of 1-piece acrylic and plate-haptic silicone toric intraocular lenses in Asian eyes. *J Cataract Refract Surg.* 2012;38:620-4.
80. Davison JA, Simpson MJ. History and development of the apodized diffractive intraocular lens. *J Cataract Refract Surg.* 2006;32:849-58.
81. Portney V. Light distribution in diffractive multifocal optics and its optimization. *J Cataract Refract Surg.* 2011;37:2053-9.
82. Rosen E, Alió JL, Dick HB, Dell S, Slade S. Efficacy and safety of multifocal intraocular lenses following cataract and refractive lens exchange: Metaanalysis of peer-reviewed publications. *J Cataract Refract Surg.* 2016;42:310-28.
83. Hood CT, Sugar A. Subjective complaints after cataract surgery: common causes and management strategies. *Curr Opin Ophthalmol.* 2015;26:45-9.
84. Braga-Mele R, Chang D, Dewey S, et al. Multifocal intraocular lenses: relative indications and contraindications for implantation. *J Cataract Refract Surg.* 2014;40:313-22.
85. Beiko G. Status of accommodative intraocular lenses. *Curr Opin Ophthalmol.* 2007;18:74-9.
86. Tomás-Juan J, Murueta-Goyena Larrañaga A. Axial movement of the dual-optic accommodating intraocular lens for the correction of the presbyopia: optical performance and clinical outcomes. *J Optom.* 2015;8:67-76.
87. Pérez-Merino P, Birkenfeld J, Dorronsoro C, et al. Aberrometry in patients implanted with accommodative intraocular lenses. *Am J Ophthalmol.* 2014;157:1077-89.
88. 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.