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Presbyopia Correction at the Time of Cataract Surgery

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Abstract

Purpose of Review In this article, we review the latest research related to presbyopia management at the time of cataract surgery with attention focused on available options in the USA.

Recent Findings With refractive cataract surgery, patient satisfaction is largely dependent on preoperative expectations with regard to spectacle independence and photic phenomena. Monovision with monofocal intraocular lenses have the highest rates of spectacle dependence but the lowest rate of photic phenomena. Extended depth of focus lenses provides excellent distance and intermediate vision, but patients often require glasses for near vision in addition to having mild glare and halos. Refractive multifocal lenses tend to have the highest rates of photic phenomena. Both diffractive and refractive multifocal lenses had excellent near and distance visual acuity but difficulty with intermediate vision. Trifocal lenses provided the most consistent vision at near, intermediate, and distance and only had moderate amounts of glare and halos with excellent patient satisfaction.

Summary The current market of intraocular lenses provides patients with the opportunity to experience spectacle independence following refractive cataract surgery. Current options include monovision with monofocal lenses, multifocal intraocular lenses, extended depth of focus intraocular lenses, and pseudo-accomodative intraocular lenses. Future technology is focusing on accommodation, pinhole apertures, and improved multifocality.

Keywords Refractive cataract surgery · Presbyopia · Monovision · Multifocal IOL · Trifocal IOL · Extended depth of focus IOL · Accommodative IOL

Introduction

Cataract surgery is the most widely performed surgery in the world and has overwhelmingly favorable results. With modern phacoemulsification techniques, visual recovery can occur within days [1]. Typically, the crystalline lens is emulsified and replaced with an intraocular lens (IOL) powered specifically for the patient to correct for positive or negative defocus. Additionally, toric IOL implants are available for management of astigmatism. Standard cataract surgery with a monofocal lens in each eye results in surgically induced presbyopia, which necessitates near-vision correction with bifocals or reading glasses. IOL technology has evolved rapidly in recent years and now provides patients with increasingly broad options for presbyopia correction and reduced dependence on spectacles following cataract surgery. The key to achieving the best quality for vision and ultimately happy patients is to nail the refractive outcome. Eliminating the residual refractive error either by a perfect outcome from surgery or by doing a laser fine-tune reduces many of the negative side effects of the newer IOL technologies.

Presbyopia

Accommodation refers to the change in refractive status of an eye when focused at near [2, 3]. Due to progressive hardening of the lens and weakening of the ciliary muscle, progressive loss of accommodation occurs—otherwise known as presbyopia. This process occurs naturally and results in most individuals requiring near-vision correction by the age of 50 [2, 4]. Additionally, cataract surgery with implantation of a monofocal IOL results in immediate and absolute presbyopia. In an effort to provide less dependence on spectacles, numerous lenticular, corneal, and

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scleral surgical techniques have been developed [5]. The remainder of this review will be dedicated to the surgical approach of managing presbyopia at the time of cataract surgery.

Intraocular Lens Options

Intraocular lens technology is rapidly evolving, but at this point in time, there are a finite number of implant options available in the USA. Monofocal intraocular lenses provide a single focal point for targeted vision correction [6]. Multifocal intraocular lenses offer two (bifocal) or three (trifocal) discrete focal points to allow for a broader range of vision [3]. Extended depth of focus (EDOF) lenses aim to create a single elongated focal point to enhance the range of vision [7••]. Accommodative IOLs change axial position inside of the eye with ciliary muscle contraction and induce an overall power change within the eye [8]. While available globally, but not the USA, pinhole IOLs aim to increase depth of focus and therefore allow for "pseudoaccommodation" [9].

Reporting of Outcomes

Although there has been a recent push to standardize the reporting of outcomes of IOL surgery [10], there is no current consensus. However, there are numerous commonly reported objective and subjective outcomes when publishing on refractive cataract surgery. The uncorrected distance visual acuity (UCVA) at distance, intermediate, and near is the primary measure of spectacle independence, while the best corrected visual acuity (BCVA) at distance, intermediate, and near represents the spectacle corrected vision. These values are typically presented in LogMAR with + 0.2, or 20/32 vision, representing an acceptable result [2, 11]. With this data, defocus curves can be created.

While visual acuity is a measure of the spatial-resolving ability of the visual system under high contrast, contrast sensitivity (CS) is a measure of the ability to distinguish fine increments of light versus dark. Due to the light-splitting nature of certain IOLs, contrast sensitivity may be affected and is therefore an important outcome measure. Photic phenomena are visual artifacts that may be experienced by patients following cataract surgery. Glare refers to reduction in visual acuity with increased luminescence, or brightness. Halos are the perception of a diffused ring surrounding a light source. Finally, and perhaps most importantly, is measurement and reporting of patient satisfaction following IOL implantation.

Pseudophakic Monovision with Monofocal IOLs

First described in 1984 by Boerner and Thrasher, pseudophakic monovision aims to provide binocular spectacle independence via implantation of monofocal intraocular lenses with targeted anisometropia [12]. Classically, the dominant eye is set for emmetropia at distance, while the non-dominant eye is made slightly myopic so that the far-point of the eye allows for intermediate or near vision. While historically the non-dominant eye was set for − 2.5 diopters (D) of anisometropia, this was often intolerable by the patient. As such, eyes are now targeted for less myopia on the order of − 1.25 to − 1.75 D. Further, mini-monovision emerged targeting patients to even less myopia, between − 0.75 and − 1.25 D [2, 13, 14••, 15••, 16].

Lens Options

The technique of pseudophakic monovision works with all monofocal IOLs with any design of the optic or haptic. However, use of an aberration-free, aspheric lens (Akreos AO, Bausch and Lomb, USA) does not correct positive spherical aberrations of the cornea and therefore may provide slightly increased depth of focus [13]. Additionally, the RxSight Light Adjustable IOL (LAL) now provides the ability to personalize post-operative monofocal refraction and may ultimately provide the most reliable pseudophakic monovision [17]. Finally, monovision is still possible to achieve in eyes with poor capsular support by utilizing anterior chamber and scleral or iris-fixated IOLs.

Uncorrected Visual Acuity

Mini-monovision with the dominant eye targeting emmetropia and the non-dominant eye set to − 1.5 D leads to excellent bilateral uncorrected distance visual acuity (UCDVA) of 0.2 logMAR or better in over 90% of patients, while the uncorrected intermediate visual acuity (UCIVA) was 0.2 logMAR or better in around 85% of patients. As expected with low myopic corrections, uncorrected near visual acuity (UCNVA) was 0.2 logMAR or better in less than half of all patients [13, 14••, 15••, 16].

Spectacle Independence

With reliably improved distance and intermediate vision, over 90% of patients are spectacle independent for distance and computer usage following refractive cataract surgery with pseudophakic monovision [18•]. Around 20% of patients still required glasses for reading and night driving [11, 13].

Contrast Sensitivity

There is conflicting data surrounding the impact of pseudophakic monovision on contrast sensitivity. Compared with bilateral emmetropic correction, monovision may result in slight decreases in contrast sensitivity (CS). Decreased CS is particularly prominent under scotopic conditions. There is less reduction of contrast sensitivity in pseudophakic monovision compared with bilateral distance corrected bifocal IOLs but potentially slightly more reduction than EDOF or trifocal lenses [13, 14••, 15••, 16].

Photic Phenomena

Over 60% of pseudophakic monovision patients report some degree of glare, while less than 20% experience halos. The glare is likely caused by the residual refractive error of the non-dominant eye and is reduced when the refractive error is corrected. These rates were only slightly higher than patients targeted for bilateral emmetropia. These rates were repeatedly lower than reported for multifocal IOLs [14••].

Patient Satisfaction

On average, patients were very satisfied with pseudophakic monovision. Around 85% of patients state that they would undergo the same procedure if given the opportunity. Unique factors to pseudophakic monovision are the added benefit of cost reduction as monofocal IOLs are typically covered by insurance. Conversely, cortical adaptation is crucial for patient satisfaction, and therefore it is recommended to do a contact lens trial to see if the patient can tolerate anisometropia. This can be challenging if a patient has already developed a cataract as the quality of vision may not be good enough for a fair trial of monovision. The author of this paper does not routinely do a contact lens trial prior to cataract and had previously only done pseudophakic monovision on patients without previous monovision experience on a limited basis. With the introduction of the light-adjustable lens, the customized monovision and slight anecdotal extended depth of focus that can come from the adjustments has started to do that more routinely, understanding that the IOL can be adjusted back to binocular distance vision if the patient desires. Patients are significantly less likely to undergo IOL exchange with monovision compared with multifocality [18•]. Both mini-monovision and full-monovision provides similar levels of patient satisfaction [14••, 15••, 16].

Special Considerations

With any anisometropia, there is a risk of decrease in stereoacuity. Depending on the level of induced anisometropia, the percentage of patients with preserved stereopsis ranged from 63 to 87% [15••]. This is a significant reduction compared with bilateral emmetropic monofocal IOLs or multifocal IOLs. Numerous studies have determined that the ideal target is 1.5–1.75 D of anisometropia for the widest range of vision [15••].

Conclusion

Pseudophakic monovision is a cost-effective, viable option for presbyopia correction at the time of cataract surgery. Though the rates of spectacle independence are lower than with multifocal IOL implantation, there are less photic phenomena—overall, there is high patient satisfaction.

Multifocal IOL

Available since the 1980s, multifocal intraocular lenses (MIOL) have undergone significant advancements [19]. By definition, multifocality implies that light is divided into two or more foci [20]. The ultimate goal with a multifocal IOL is to provide excellent distance and intermediate and near vision with limited need for spectacle correction.

Lens Options

Generally, there are two main categories of multifocal IOLs—refractive and diffractive, though a lens can be a combination of the two. Refractive IOLs contain concentric zones of increasing dioptric power with the highest power present in the center. The near reflex provides miosis, and therefore more light is concentrated centrally on the highest add power, allowing for reading at near. Due to its design, refractive IOLs are sensitive to lens centration, angle kappa, and pupil size. Additionally, due to the rough areas between zones, there is a significant loss of contrast sensitivity. Therefore, most modern multifocal IOLs are at least partially diffractive. Apodization is the term describing decreasing height of concentric diffractive rings surrounding a near-dominant central area. Generally, the bifocal IOLs are available with different add values to provide a patient with better near (high add) or intermediate (low add) vision [2, 19]. As of 2019, the only trifocal IOL available in the USA is the Alcon PanOptix. Refer to Table 1 for a listing of all available multifocal IOLs.

Uncorrected Visual Acuity

For the PanOptix trifocal IOL, 96% of patients have UCDVA ≤ 0.2 logMAR, 94% of patients have UCIVA ≤ 0.2 logMAR, and 91% have UCNVA ≤ 0.2 logMAR [21•,22–24]. Comparatively, patients implanted with bilateral apodized diffractive bifocal IOLs have similar UCDA and UNVA, but significantly worse UCIVA [2,3,14••,19]. Certain studies

Table 1 Multifocal and extended depth of docus IOLs available in the USA

Manufacturer	IOL platform	IOL model	Focality	Optical principal	Structure	Add power IOL plane (D)	Add power spectacle plane (D)	Toric availability
Johnson and Johnson	TECNIS	ZKBOO	Bifocal	Diffractive	Constant	+ 2.75	+ 2.00	NO
	TECNIS	ZLBOO	Bifocal	Diffractive	Constant	+ 3.25	+ 2.50	NO
	TECNIS	ZXROO (Symfony)	EDOF	Diffractive	Achromate	+ 1.75	+ 1.50	YES
Alcon	Acrysof IQ	ReSTOR SV25T0 (ACTIVEFOCUS)	Bifocal	Refractive-Diffractive	Apodized	+ 2.50	+ 2.00	YES
	Acrysof IQ	ReSTOR SN6AD1	Bifocal	Refractive-Diffractive	Apodized	+ 3.00	+ 2.50	YES
	Acrysof IQ	TNFTN00 (PanOptix)	Trifocal	Refractive-Diffractive	Constant	+ 1.75 and + 3.00	+ 1.50 and + 2.50	YES

show a trend toward improved UCDVA in bifocal IOL group compared with trifocal, although the results are conflicting [25,26•]. Ultimately, implantation with both bifocal and trifocal IOLs lead to acceptable distance and near visual acuity, but trifocal IOLs also provide the added benefit of intermediate vision.

Spectacle Independence

For the PanOptix, around 95% of patients experience spectacle independence for all activities. Of those that require correction, it is typically due to inaccurate preoperative IOL calculations leading to the wrong powered lens [26•,27]. Conversely, implantation with a bifocal IOL leads to spectacle independence around 73% of the time. While the distance and near vision may be acceptable without correction with bifocal IOLs, computer use is often challenging owing to the reduced UCIVA [3,19,26•].

Contrast Sensitivity

Studies evaluating contrast sensitivity in MIOLs present conflicting results. Though older refractive models suffered from decreased contrast sensitivity, it is now believed that current model diffractive IOLs do not significantly reduce contrast sensitivity beyond standard monofocal IOL implantation [14••,23,28,29].

Photic Phenomena

For all current MFIOLs, around 30% of patients experience photic phenomena. Of the individuals who experience photic phenomena, halos are present in over 85% and glare is present in around 10%. Interestingly, most patients report that the halos are not bothersome at all [22, 28, 30].

Patient Satisfaction

For the PanOptix, over 90% of patients stated that they would choose the same IOL again and recommend it to others [3, 23, 27]. Comparatively, around 70% of patients with bifocal MIOLs would choose the same lens [23, 28]. The most common cause for dissatisfaction with all MIOL was residual ametropia. The resulting refractive error can easily be fixed by laser vision correction and usually reduce or eliminate any dissatisfaction. Photic phenomenon are responsible for 38.2% of all dissatisfaction with MIOL [30].

Mix-and-Match Bifocal

Cataract surgery with implantation of two distinct bifocal IOLs with different add values (i.e. ReSTOR + 2.5/+ 3) is an option that has been explored by numerous surgeons. While patient satisfaction and spectacle independence is marginally, though not statistically, higher than patients without a mix-and-match approach with bilateral bifocal implantation, there is no significant gains in uncorrected intermediate visual acuity [2,19,26•,31•,32••, 33, 34]. Additionally, some studies have found that UCDVA is inferior in the blended approach compared with bilateral implantation of trifocal IOLs [26•]. Therefore, with the introduction of trifocal IOLs into the market, the mix-and-match technique may become obsolete.

Special Considerations

Although the diffractive or combined refractive-diffractive IOLs are less dependent on angle kappa, centration, and pupil size, these factors as still worth considering [2]. Poor capsular support should exclude patients from receiving a multifocal IOL. Adequate sizing and centration of the capsulorrhexis is critical for long term stability. Notably, the PanOptix lens is nonapodized and therefore has relatively constant optical properties over the optical zone. This makes the lens less sensitive to moderate changes in pupil size and IOL decentration [35].

Conclusion

Multifocal IOLs provide a much wider range of vision than monofocal IOLs. Bifocal and trifocal IOLs provide comparable distance and near vision, but trifocal IOLs lead to better uncorrected intermediate vision. Photic phenomena are more prevalent than in monofocal or extended depth of focus lenses.

Extended Depth of Focus IOL

Compared with monofocal or multifocal lenses that divide light at discrete foci, extended depth of focus (EDOF) intraocular lenses work by focusing incoming waves in an extended longitudinal plane to create a wider range of vision [7••].

Lens Options

At the time of this writing, the TECNIS Symfony lens is the only available EDOF in the USA. This lens has a biconvex wavefront-designed anterior aspheric surface and a posterior achromatic diffractive surface. Internationally, there are more options including IOLs with a central aperture to improve depth of focus [9].

Uncorrected Visual Acuity

When bilateral EDOF implantation is targeted for emmetropia at distance, the UCVDA is ≤ 0.2 logMAR 96% of the time, while UCIVA is ≤ 0.2 logMAR 90% of the time. Conversely, the UCVNA is ≤ 0.2 logMAR only 41% of the time. Compared with trifocal lenses, there is marginally improved distance vision, comparable intermediate vision, but significantly worse near vision. Compared with bifocal lenses, there is comparable distance vision but improved intermediate vision, while the near vision is worse [7••,11,21•,23,33,35–38]. Comparatively, when a mini-monovision, or blended, approach is used with two EDOF lenses, patients achieve improved UCNVA with an average of 0.19 logMAR without sacrificing UCDVA or UCIVA [28,31•,39].

Spectacle Independence

Around 75% of patients report spectacle independence for all activities with the Symfony EDOF lens. A total of 95% of patients were spectacle independent for distance and 85% for intermediate activities. With a mini-monovision approach, over 95% of patients achieved spectacle independence for all activities [7••,11,19,31•].

Contrast Sensitivity

One of the benefits of EDOF is that there is no significant reduction in contrast sensitivity [21•,23].

Photic Phenomena

Compared with MIOLs, EDOF lenses have significantly less photic phenomena at around 15%. Interestingly, EDOFs have a unique photic phenomena typically described as "starbursts" [19,21•,40••].

Patient Satisfaction

Overall, patients are very satisfied with EDOF lenses: over 90% state that they would have the same lens if they needed surgery again [2,7••,21•,31•].

Conclusion

Extended depth of focus lenses provide quality distance and intermediate vision, but lack the UCNVA offered by multifocal IOLs. There are less photic phenomena with EDOFs than with MIOLs. By using a blended approach, patients can achieve even greater rates of spectacle independence without compromising their distance or intermediate vision.

Accommodative IOL

By definition, an accommodating IOL must have a dynamic increase in dioptric power with an effort to focus from distance to near vergence. While restoration of accommodation is the ultimate goal, there is no available IOL that fully mimics the natural accommodative mechanism [8]. Instead, the concept of "pseudoaccommodative" IOLs have emerged whereby a lens can increase its dioptric power through change in axial position, induction of higher order aberrations, or lens tilt [41, 42].

Lens Options

While there are a number of accommodative IOLs in development internationally, the Crystalens (Bausch and Lomb, Rochester, NY, USA) is the only commercially available accommodative IOL in the USA. In theory, the lens works by hinging anteriorly with ciliary muscle contraction, thereby increasing the overall power of the eye. Additionally, the center of the IOL is biaspheric, which increases the depth of focus to provide better intermediate and near vision [41, 43]. While argued that the lens provides up to 1 D, in ray tracings, the Crystalens has been shown to increase its power by 0.4 D with near focus [8].

Uncorrected Visual Acuity

As with monofocal, multifocal, and EDOF lenses, the UDCVA is excellent with 97% of patients achieving ≤ 0.2 logMAR when the refractive target is within 0.5 D with bilateral implantation. 98% of patients experienced UCIVA ≤ 0.2 logMAR. Additionally, 84% of patients experienced UCNVA ≤ 0.2 logMAR vision with bilateral implantation [43]. While these numbers were published in the clinical trial that led to FDA approval of the IOL, many surgeons feel that these numbers can only be achieved by implementing mini-monovision

with the non-dominant eye targeted for around −0.75 to −1.25 D. Additionally, defocus curves constructed with bilateral Crystalens implants has been shown to be poor [8,31•,41,44]. Refer to Fig. 1 for defocus curves of available IOLs in the USA.

Spectacle Independence

With bilateral implantation of the Crystalens targeted for distance, around 45% of patients still require near vision correction. However, with the mini-monovision approach over 85% of patients achieve spectacle independence at all distances [8,31•].

Contrast Sensitivity

Contrast sensitivity is not reduced compared with standard monofocal IOLs. In fact, some studies indicate a more favorable CS profile, particularly in photopic conditions [8, 41].

Photic Phenomena

Around 50% of patients describe some form of photic phenomenon, most commonly glare. Like the multifocal cohort, the patients were not bothered by the glare [8, 44, 45].

Patient Satisfaction

Over 90% of patients are satisfied with their bilateral Crystalens implant,and 81% would refer a family member to have the same procedure [45].

Special Considerations

Unique to the Crystalens is a condition known as asymmetric capsular contraction, or Z-syndrome. With asymmetric capsular contraction, the plate haptics vault in opposite direction. This induces astigmatism and decreased quality of vision that often necessitates an IOL exchange. Intraoperative measures taken to prevent Z-syndrome include a properly sized central capsulorrhexis with adequate coverage of the plate haptics and meticulous cortical removal. Some surgeons recommend polishing of the anterior capsular leaflets [2, 8, 41, 44].

Conclusion

The Crystalens is the only available accommodative IOL in the USA and works, in theory, via anterior vaulting of the optic during near focus. While the defocus curve does not demonstrate significant amounts of dioptric gain with near vergence, patients are often satisfied with their spectacle independence, particularly when a mini-monovision approach is taken.

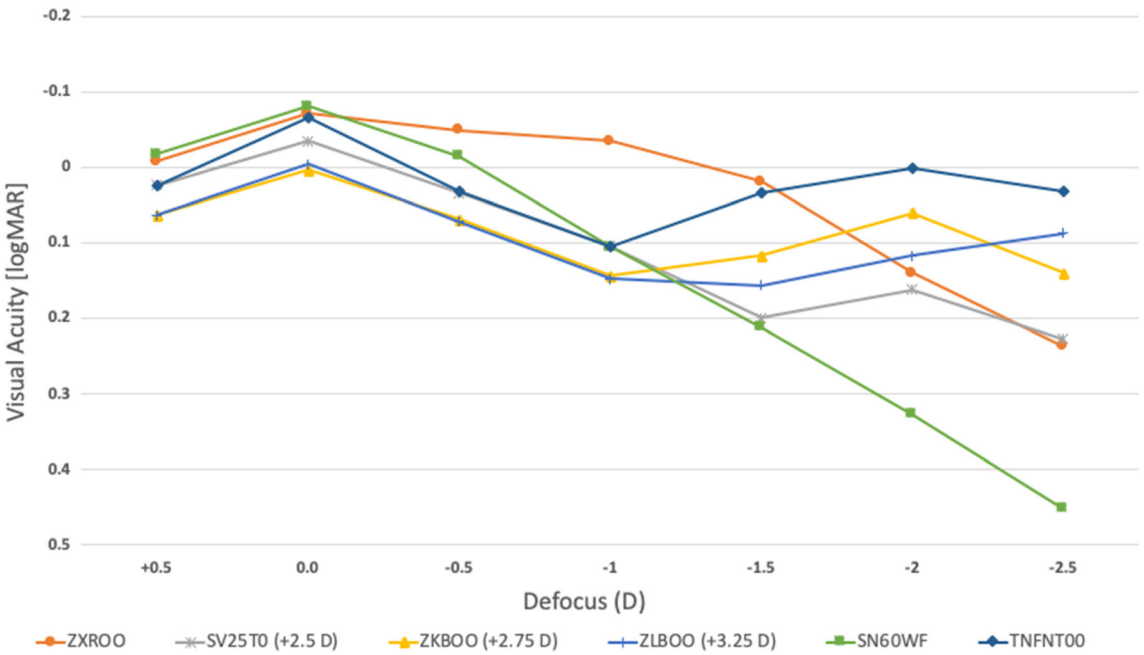

Fig. 1 Defocus Curves of IOLs Available in US

Discussion

It truly is a great time to be a refractive cataract surgeon. The explosion of technology with modern IOLs has made presbyopia correction much easier for surgeons and has provided much better outcomes for patients. The advent of low-add multifocal IOLs brought in an era of quality vision at multiple distances, with a much-improved side effect profile. Surgeons were able to confidently recommend these IOLs for patients, knowing that the quality of vision was satisfactory and approaching that of a monofocal and could help patients understand the glare and halo that would follow would likely be tolerable. Once comfortable with the low-add multifocal IOLs, surgeons were then able to mix-and-match the various low-add multifocal IOLs to further improve the range of vision patients could achieve and do even more without spectacles, especially at near. The entrance of extended depth of focus IOLs allowed us to have even more flexibility with our IOL options. Surgeons had multiple tools in their toolbox that would allow them to customize the options to patients without sacrificing quality of vision.

The approval of the trifocal IOL in the USA has made our lens options even better. One of the main advantages of the trifocal IOL is, because it provides quality distance, intermediate, and near vision, both eyes can have the same IOL implanted. This allows for synergy between the eyes, allowing for even better quality of vision. And, since both eyes have the same IOL, the neuroadaptation process can happen much faster, diminishing negative visual side effects. As a bonus, the trifocal is available in a toric version, allowing for astigmatism correction at the time of surgery.

Since the introduction of the trifocal IOL, it has become our preferred IOL for the reasons mentioned above. However, there is still a role for the other IOLs depending on surgeon and patient preference. The Light Adjustable Lens has truly been a game-changer for our practice as we are able to adjust the IOL after cataract surgery for the first time ever. We have learned that although it is only a monofocal IOL, it seems to have some extended range of vision after the adjustments. There is no published data surrounding this, however. From our clinical experience, patients are able to tolerate the mini-monovision much better than with standard monofocal IOLs. The distance eye gets precise distance vision with some near vision, and the near eye will get very good near vision with only a small amount of myopia that minimally impacts the distance vision. With binocular vision, these patients are able to achieve a spectacle free life for most of their activities.

It is important to note that MFIOL are very sensitive to posterior capsule opacity (PCO) and, when present, will affect the near vision first. We have a low threshold to YAG any PCO that may be present as it will improve the near vision and also reduce any glare or halo that is present. It is equally important to remember that any residual refractive error will result in an unsatisfied patient, due to decreased visual acuity or increased glare, halo, etc. The residual refractive error can easily be corrected with laser vision correction and allow these patients to have quality vision at distance, intermediate, and near, with minimal need for spectacle correction. With technology continuing to improve for the LAL and trifocal and beyond, the future is bright!

Conclusion

With the goal of providing spectacle independence at the time of cataract surgery, intraocular lens technology has improved dramatically in recent years. While patient satisfaction is comparable among all options, bilateral implantation with a trifocal IOL provides the highest rate of spectacle independence with satisfactory distance, intermediate, and near visual acuity. Pseudophakic monovision with monofocal IOLs remains a viable, cost-effective option but requires cortical adaptation to tolerate anisometropia and stereoacuity is reduced. Bifocal IOLs provide quality distance and near vision, while EDOF lenses provide quality distance and intermediate vision. Taking a mix-and-match approach with bifocal IOLs has marginal benefit. A blended approach with mini-monovision with both accommodating IOLs and EDOF lenses provides higher rates of spectacle independence compared with bilateral distance emmetropia.

Compliance with Ethical Standards

Conflict of Interest Brian M. Shafer and Michael Greenwood both declare no potential conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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