Review Article

Optimizing outcomes with multifocal intraocular lenses

Gitansha Shreyas Sachdev, Mahipal Sachdev[1]

Modern day cataract surgery is evolving from a visual restorative to a refractive procedure. The advent of multifocal intraocular lenses (MFIOLs) allows greater spectacle independence and increased quality of life postoperatively. Since the inception in 1980s, MFIOLs have undergone various technical advancements including trifocal and extended depth of vision implants more recently. A thorough preoperative workup including the patients' visual needs and inherent ocular anatomy allows us to achieve superior outcomes. This review offers a comprehensive overview of the various types of MFIOLs and principles of optimizing outcomes through a comprehensive preoperative screening and management of postoperative complications.

Key words: Diffractive intraocular lens, intraocular lens, multifocal intraocular lens, presbyopia-correcting intraocular lens

Access this article online
Website:
www.ijo.in
DOI:
10.4103/ijo.IJO_1072_17
Quick Response Code:

Cataract surgery today is fast evolving into a refractive procedure, with a transition in the postoperative goal from visual restoration to emmetropia. Parallel to the improvements in instrumentation and techniques of cataract removal, the intraocular lenses have undergone various developments. Multifocal intraocular lens (MFIOL) implants afford postoperative spectacle-free vision for both distance and near.

The review article provides a comprehensive overview of the various types of multifocal intraocular implants, preoperative evaluation and planning to enhance surgical outcomes, visual results thus far and postoperative complications and management of dissatisfied patients.

The literature search was performed in MEDLINE using "multifocal intraocular lenses," "diffractive multifocal lenses," "refractive multifocal lenses," "cataract surgery," and "presbyopia-correcting intraocular lenses" as keywords. The relevant references cited in the articles were searched additionally. For references frequently cited in the manuscript files, the earliest reference was chosen for citation.

Types of Multifocal Intraocular Lenses

Accommodation, a property of the young crystalline lens allows focus for both distance and near vision. This is generally lost as the person ages or following cataract surgery wherein the natural lens is replaced with a monofocal intraocular lens. Presbyopia-correcting intraocular lenses (IOLs) including MFIOLs provide spectacle independence for both near and distance vision.

Three general optic principles have been applied to provide multifocality in the present day IOLs: multizonal refractive, diffractive, and extended range of vision (EROV) designs.

Refractive IOLs use concentric or annular ring-shaped zones of varying dioptric powers. With changes in the pupil diameter in response to illumination and accommodation, the number of zones in use vary redistributing the proportion of light directed for distance and near. Hence, the image quality and energy balance is pupil dependent.[1,2]

Diffractive IOLs are engineered with microscopic steps of a specific phase delay, usually half a wavelength: Huygens–Fresnel principle. Light encountering these steps is directed equally between distant and near focal points for all pupil diameters. A portion of the light energy of around 18% is directed into higher diffraction orders, with the remaining distributed equally for distance and near, i.e., 41% each.

The principle of *apodisation* was based on the greater need for distance vision in conditions of dim illumination (when pupils are large). In addition, a greater focus of light to the distant focal point reduces the defocused near light with its subsequent visual phenomena of glare and halos.[3] This is achieved by a gradual reduction in diffractive step heights from center to periphery, and a subsequent distance-dominant lens for large pupils.[4]

EROV or extended depth of focus (EDOF) IOLs: The Symfony IOL (Tecnis, Abbott Medical Optics Inc., Johnson and Johnson vision) combines a unique diffractive pattern

The Eye Foundation 582A, DB Road, RS Puram, Coimbatore, Tamil Nadu, India, [1]Chairman and Medical Director, Centre for Sight, B-5/24, Safdarjung Enclave, New Delhi, India

Correspondence to: Dr. Gitansha Shreyas Sachdev, The Eye Foundation, 582A, DB Road, RS Puram, Coimbatore - 641 002, Tamil Nadu, India. E-mail: sachdevgitansha@gmail.com

Manuscript received: 01.11.17; Revision accepted: 09.11.17

Cite this article as: Sachdev GS, Sachdev M. Optimizing outcomes with multifocal intraocular lenses. Indian J Ophthalmol 2017;65:1294-300.

with achromatic technology and a proprietary echelette design resulting in an elongated depth of focus.

Trifocal IOLs with three focal points have been introduced to overcome the limitations associated with prior bifocal models.[5] The additional intermediate focus provides superior quality of vision for intermediate activities.

Table 1 highlights the characteristics of the commonly used MFIOLs.

Preoperative Evaluation and Planning

The choice of the intraocular lens is determined by the patient's lifestyle and expectations. Excessively critical patients or those with unrealistic expectations are not ideal for a MFIOL.[6] The ideal choice of a MFIOL is based on the patient's visual activities and tolerance to nighttime dysphotopsia. It is imperative to provide adequate counseling regarding the possibility of a loss of contrast and temporary nighttime dysphotopsia in exchange for a broader range of vision postoperatively. In addition, the inherent ocular anatomy and physiology should be considered, and comorbidities which may affect the visual outcomes should be excluded.

Corneal astigmatism

Corneal astigmatism of 1.25 D or more is prevalent in approximately 30% of the eyes undergoing cataract surgery.[7,8] Preoperative keratometry utilizing manual, automated, or partial coherence interferometry can help determine the extent and placement of the cylindrical power. A regular corneal astigmatism with repeatability on various measuring devices would serve as an ideal case for multifocal lens implantation. Corneal topography devices such as the Pentacam (Oculus, Inc.) and intraoperative aberrometry (Ocular Response Analyzer, Wavetec Vision) can additionally estimate posterior corneal astigmatism.[9]

Astigmatism management is of paramount importance for obtaining ideal postoperative results with MFIOLs. A postoperative astigmatic error exceeding three-quarters of a diopter results in significant decline in visual quality.[10] The astigmatism can be managed concurrently by limbal relaxing incisions or arcuate keratotomies, opposite clear corneal incisions or the implantation of a toric IOL, the results with the former being less predictable and prone to regression with time.[11,12]

Corneal ablative procedures have demonstrated success in correcting the residual refractive error. However, it is imperative to allow adequate healing of the corneal incision and stabilization of corneal topography before attempted correction. In addition, ocular surface health should be confirmed as these patients constitute an elderly population and systemic factors such as diabetes which may interfere with wound healing should be well controlled.[13,14]

Corneal and external eye disease

Preoperative evaluation and subsequent management of ocular surface disorders such as dry eye, blepharitis, and meibomium

Table 1: Characteristics of commonly used multifocal intraocular lenses

	Type of optic	Optic diameter (mm)	IOL material	Add at lenticular plane (D)	Light distribution
ReZoom (AMO)	Refractive surface	6	UV blocking hydrophobic acrylic	+3.0 D for near	Pupil dependent
ReSTOR (Alcon)	Anodized anterior diffractive surface plus refractive base	6	UV blocking hydrophobic acrylic	+3.0 D for near (SN6AD1) +2.50 D for near (SN6AD2)	Pupil dependent
Tecnis Multifocal (AMO)	Posterior nonapodized diffractive surface	6	Hydrophobic acrylic	+4.0 (ZMB00) +3.25 (ZLB00) +2.75 (ZKB00)	41% near 41% distance
AT LISA 809 (Carl Zeiss)	Posterior nonapodized diffractive surface	6	Hydrophilic acrylic (25%) with hydrophobic surface	+3.75 D for near	35% near 65% distance
Tecnis Symfony (Johnsons and Johnsons Vision)	Anterior aspheric with posterior achromatic diffractive surface with echelette design	6	UV blocking Hydrophobic acrylic	Extended depth of focus (ZXR00)	Pupil independent
AT LISA tri 839 MP (Zeiss)	Trifocal aspheric diffractive	6	Hydrophilic acrylic (25%) with hydrophobic surface properties	+3.33 D near add and +1.66 D intermediate add	50% near, 20% intermediate, 30% near
Acrysof IQ PanOptix	Inner diffractive with outer refractive zone	6	UV filtering aspheric hydrophobic acrylic	+3.25 D near add and +2.17 D intermediate add	
Acridiff (CARE group)	Apodized diffractive	6	UV blocking hydrophobic acrylic	+3.25 D near add	40% near, 60% distance
Infocus (Supraphob)	Anterior: Refractive EDOF and micro diffractive optic with aspheric posterior surface	6	UV blocking hydrophobic acrylic	Extended depth of focus	Pupil independent

IOL: Intraocular lens, UV: Ultraviolet, EDOF: Extended depth of focus gland dysfunction greatly aids in improving visual outcomes. Although dry eye may be considered as a postoperative condition in previously asymptomatic individuals, in most cases, it consists of worsening of a prior condition due to disruption of corneal neuroarchitecture and reduced corneal sensitivity.[15]

Dry eye along with residual refractive error has been reported as the most common cause of dissatisfaction in patients with multifocal implants.[16,17]

An aggressive preoperative evaluation for ocular surface disease and treatment in subclinical cases is mandatory. Donnenfeld and coworkers studied the results of a 3-month treatment regimen (1 month preoperative till 2 months' postoperatively) with cyclosporine 0.05% on the visual outcomes of patients implanted with MFIOLs.[18]

They reported a significantly better uncorrected and corrected visual acuity as compared to the control group (artificial tear supplementation). Additionally, improved contrast sensitivity, conjunctival staining, and tear film break up time was noted.

Corneal pathologies such as dystrophies, scars, and large pterygia may influence the visual outcomes. Peripheral or visually insignificant corneal scars are not considered a contraindication for MFIOLs. The presence of pterygium and subsequent excision significantly influences the corneal astigmatism,with larger pterygia exerting a greater effect.[19] In such cases, a sequential approach of pterygium excision followed by cataract surgery should be adopted.

Previous refractive surgery or corneal aberrations

Patients with prior refractive surgery would intuitively constitute a large proportion of the candidates opting for multifocal implants, due to their desire to be free from spectacles from the very beginning. However, highly aberrated corneas such as keratoconus or prior refractive surgery are associated with a decreased contrast sensitivity, which in turn would experience a further deterioration following a multifocal implant. Intolerable dysphotopsia following diffractive MFIOLs has been reported with an anterior corneal coma >0.32 um.[20]

Limited studies are available on the visual results of MFIOLs in eyes with previous refractive surgery. Alfonso *et al*. compared visual outcomes following the implantation of hybrid refractive-diffractive multifocal lenses with aspheric monofocal IOLs in 80 eyes with prior laser vision correction.[21] The multifocal group demonstrated lower best corrected visual acuity (BDVA) under photopic conditions with glare or low contrast and mesopic conditions at all levels of contrast. The authors concluded that the aspheric nature of the monofocal implant compensated somewhat for the increased spherical aberrations after myopic laser *in situ* keratomileusis (LASIK).

Similar results were noted while comparing the visual function in eyes implanted with the ReSTOR SN60D3 IOL versus phakic eyes after hyperopic LASIK.[22] Fernandez-Vega *et al.* published their data demonstrating a loss of one or more lines of BDVA in 27.82% (6 eyes) in the multifocal group versus 3.84% (1 eye) in the aspheric monofocal group.[23]

Intraocular lens power calculation poses an additional challenge in these eyes with less predictable outcomes as compared to normal eyes.[24,25] Muftuoglu *et al.* in 2010 published the results following MFIOL implantation (ReSTOR SA60D3 and ReSTOR SN60D3) in 49 eyes that had the previous LASIK for myopia.[26] No single formula was used uniformly for all patients. At 1 month, 32 eyes (65%) and 41 eyes (84%) had a residual spherical equivalent within ±0.50D and ±1.0 D of emmetropia, respectively. Twenty eyes underwent subsequent enhancement, highlighting the degree of dissatisfaction following initial outcomes.

Khoramnia *et al.* reported a case of binocular multifocal implantation (customized Lentis Mplus LU-313 MF3OT) 8 years following bilateral hyperopic LASIK.[27] The Haigis–L formula was used for IOL power calculation. Three-month postoperatively, the visual acuity improved to 0.10 and 0.00 LogMAR in the right and left eye, respectively.

Further studies are required to determine the results of MFIOLs with aspheric profiles. Moreover, lacunae of data regarding postoperative patient satisfaction, spectacle independence and extent of dysphotopic symptoms need to be addressed.

Zonular weakness

Intraocular lens decentration or tilt may affect the distribution of light between the distant and near foci, compromising the visual outcomes of MFIOLs. Soda and Yaguchi demonstrated varied effects of lens decentration on visual function using modulation transfer function, but overall the results were clinically relevant with decentration > 0.7 mm.[28] Furthermore, the impact of decentration and tilt on the optical quality is more severe in nonrotational symmetric IOLs as compared to refractive-diffractive IOLs.[29]

Progressive zonular weakness, haptic deformation, and asymmetric anterior capsular opening have been reported as causes of IOL decentration.[30] Focal, nonprogressive zonular dehiscence such as in a case of trauma is not a contraindication for MFIOLs. Cases of progressive zonulopathy would warrant the implantation of capsular tension ring (CTR) for the stabilization of the bag, decrease of posterior capsular folds, and reduced late capsular contraction. Alio *et al*. first assessed the outcomes of CTR with rotationally asymmetrical MFIOLs and demonstrated improved refractive outcomes and reduced postoperative aberrations.[31] Similar results were noted by Mastropasqua in a study comparing outcomes of MFIOL implantation with or without CTR, with reduced third order aberrations in the former group.[32]

Angle kappa

Angle kappa is defined as the angular distance between the pupillary axis and the visual axis. If the angle is large the light rays from an object fall at a greater distance from the fovea, resulting in glare or halos. Karhanova *et al*. studied the importance of angle kappa for the centration of MFIOLs in a cohort of 52 eyes.[33] Temporal decentration of the IOL caused pronounced photic phenomenon, particularly in cases with larger angle kappa.

Similar results published in 2011 suggested angle kappa as a contributor to photic phenomenon in eyes with refractive multifocal implants, recommending a thorough preoperative evaluation to avoid this complication.[34]

Retinal and optic nerve head pathologies

Macular and optic nerve head abnormalities are associated with decreased contrast sensitivity.[35] Assessing the appropriateness of a multifocal implant in such cases is based on the expected progression of the disease and the efficacy of available therapy. Preoperative ocular coherence tomography evaluation of the macular and optic nerve head rules out subtle or occult pathology. Automated perimetry and macular function test are other useful adjuncts. In cases of significant or progressive pathologies, MFIOLs are contraindicated. Furthermore, impaired fundus evaluation during vitrectomy has been reported in eyes with multifocal implants.[36,37]

Gayton *et al.* demonstrated the use of multifocal implantation as an aid for magnification in eyes with age-related macular degeneration (ARMD).[38]

Twenty eyes received a multifocal implant (Acrysof Restor SN60D3) targeting a spherical equivalent of −2.0D, yielding an addition of +5.2D at the spectacle plane. All eyes maintained or improved near vision, without a severe compromise in distance visual acuity.

The preliminary results of the study may prove useful in the development of high add multifocals for magnification in eyes with ARMD.

In conclusion, a thorough preoperative evaluation and subsequent management help optimize postoperative outcomes.

Visual Outcomes

Comparison of multifocal intraocular lens types

Baumuller and coworkers evaluated the outcomes of bilaterally implanted apodized diffractive versus multizonal refractive IOLs compared to standard monofocal implants.[39] Totally, 229 patients with a follow-up duration of 6.6 ± 1.7 years with Array and 4.3 ± 1.1 years with ReSTOR were included in this study. Between the two multifocal groups spectacle independence was higher and adverse visual symptoms lower in ReSTOR patients than in Array patients ($P < 0.05$). ReSTOR patients reported a higher overall visual satisfaction than the other groups ($P < 0.001$) and rated their vision at 8.8 ± 1.8.

A meta-analysis comparing the results of refractive versus diffractive IOLs in 2014 demonstrated greater uncorrected distance vision in the refractive MFIOL group.[40]

There was no significant difference between the two groups in uncorrected intermediate visual acuity. However, in terms of near visual acuity the diffractive group performed better with faster reading speed and spectacle independence. Furthermore, glare and halo was lower.

Similar results were reported while comparing the outcomes of diffractive (ReSTOR, Tecnis ZM 900 and Acritec twinset), refractive (Array SA40N and ReZoom), and accommodative IOLs (Crystalens AT 45) in twenty studies.[41] Diffractive IOLs reported a 1.75 times greater likelihood of spectacle independence, with the ReSTOR lens exhibiting twice as high an incidence of freedom from spectacles as compared to other multifocal implants.

Although successful outcomes are reported with bifocal IOLs in terms of spectacle independence and increased quality of life, the intended level of improvement in intermediate vision varies. Recent literature demonstrates promising results with trifocal IOLs (AT LISA trifocal IOL, FineVision trifocal IOL, and Panoptix).[42-48]

Comparative literature highlights the extended reading range provided by three separate focal points as compared to earlier MFIOLs, with greater spectacle independence for all distances.[49,50]

Conversely, the presence of two out of focus images would intuitively increase the likelihood of haloes. However, the results demonstrated thus far show no increased incidence of photic phenomenon.

Clinical outcomes of a novel diffractive trifocal IOL with EDOF (Acriva Reviol Tri-ED 611) were studied following bilateral implantation in forty patients.[51] The study demonstrated a UIVA of Log MAR 0.08 ± 0.12 at 1 month and 6 months' postoperative visit. A slight but significant improvement in contrast sensitivity at 3 cpd (spatial frequency) was noted. None of the patients reported the incidence of photic phenomenon at 6 months' follow-up visit.

Multifocal intraocular lens implantation in pediatric eyes

In contrast to the aging population pediatric cataracts enjoy a complete range of accommodation preoperatively, making subsequent acceptance of presbyopic aids more difficult. Worsening of amblyopia and disruption of binocular vision may ensue postoperatively.[52] Implantation of a multifocal implant in such cases may allow rapid visual rehabilitation and reduced risk of amblyopia. However, the pediatric eyes are still growing, and spectacle dependence may return following myopic shift. Although 90% of the ocular growth is complete within the first 2 years of life, a refractive shift as large as 4 diopters has been demonstrated in the second decade of life.[53,54]

In addition, a loss of contrast following multifocal implants may lead to amblyopia. Other relevant factors to consider include an anterior displacement of the lens iris diaphragm due to greater posterior vitreous pressure and more aggressive capsular fibrosis with potential IOL decentration.

The initial results of MFIOL implantation (AMO array and SA 40N) in 35 pediatric eyes with a follow-up of 27.4 ± 12.7 months revealed a BDVA of 20/40 or better in 71% of eyes.[55] In nine bilateral cases, spectacle dependency was moderate, with only two children (22%) reporting the permanent use of an additional near correction. The remaining children were either using distance-correction only (4 patients; 44%) or no glasses at all (3 patients; 33%). Stereopsis also improved significantly after MFIOL implantation ($P = 0.01$). Complications included pupillary obscuration requiring surgical intervention (16 eyes), persistent fibrous membrane (4 eyes), and IOL decentration requiring surgical intervention (6 eyes).

In another study, a 9-year follow-up of three siblings implanted with MFIOLs (Array) for pediatric cataracts at ages 16–19 years demonstrated a refractive shift of <0.5 D in four of the six eyes.[56] None of the patients reported using glasses for routine near and distance activities.

Cristobal *et al.* published their data of MFIOL implantation (Acrysof Restor) following unilateral cataract extraction in five children between 4 and 6 years of age.[57] At final follow-up, the mean corrected distance and near visual acuity was 0.03 ± 0.06 logMAR and 0.10 ± 0.10 logMAR, respectively. No cases of IOL decentration were noted. The stereoacuity was 120 s of arc (arcsec) in 2 patients, 240 arcsec in one patient, 1980 arc sec in one patient, and nonexistent in one patient. Four patients showed fusion on the Worth 4-dot test.

Femtosecond laser-assisted cataract surgery and multifocal intraocular lens

Femtosecond laser in cataract surgery (FLACS) offers a greater precision in the critical steps including anterior capsulotomy, theoretically resulting in a more predictable effective lens position. Additionally, laser-assisted arcuate keratotomies aid in debulking corneal astigmatism, thereby improving visual outcomes. Limited data are available on the results of femtosecond cataract surgery with multifocal intraocular implants.

Lawless *et al*. compared the results of 61 consecutive eyes undergoing FLACS with ReSTOR (Alcon Laboratories Inc) SN6AD1 and 29 eyes undergoing manual phacoemulsification with the same IOL implantation.[58] No significant difference was noted in the mean uncorrected or BDVA postoperatively between the two groups. However, internal aberrations and optical quality were not studied. Moreover, by excluding all eyes with refractive astigmatism >1.0 D, the additional possible benefit of femtosecond-assisted arcuate keratotomies was not assessed.

Mihaltz *et al*. published similar results with no significant differences between uncorrected and corrected distance visual acuity between femtosecond assisted and conventional phacoemulsification with monofocal implantation.[59] However, they demonstrated significantly lower internal aberrations in the femtosecond group with the potential advantage of superior visual quality.

Hence, a comparison of internal aberrations following conventional and femtosecond-assisted cataract surgery with MFIOL implantation is an avenue that still needs exploring. Greater studies are needed to determine whether technical advancements such as the femtosecond laser translate into superior optical and visual outcomes.

Postoperative Complications

Although a high level of patient satisfaction has been reported postoperatively in numerous studies, the visual outcomes may be limited in certain situations.[60,61] Defective vision attributed to ametropia or posterior capsular opacification and dry eye are the most commonly reported causes of patient dissatisfaction.[6,16]

Defective vision

MF IOLs inherently split the available light, resulting in greater sensitivity to loss of contrast associated with residual refractive error and posterior capsular opacification.

Residual refractive error may result from various factors including inaccuracies in biometric analysis, limitations of IOL power calculation, and errors in IOL positioning.[62,63]

Rehabilitation options include spectacles, contact lenses, or surgical intervention in the form of LASIK, piggyback IOLs, or IOL exchange.[64,65]

Alfonso *et al.* studied the results following femtosecond LASIK for correction of residual refractive error.[13] About 96.2% of the eyes were within 0.50D of the desired refraction, with a gain of lines of BDVA in 11 eyes. Similar results were noted in other studies with apodized diffractive multifocal lenses.[14,66]

Outcomes comparing LASIK for myopia, hyperopia, and astigmatism following both apodized diffractive-refractive and fully diffractive IOLs revealed similar results.[67]

As the raised intraocular pressure during laser procedure can distort a recently fashioned full thickness corneal incision of cataract surgery, it is essential to wait for wound stability prior to the LASIK procedure. Additionally, systemic conditions like diabetes which may interfere with healing should be managed before surface ablation.

Optic capture through the anterior capsulorrhexis has been described as a safe and effective procedure in eyes with a mild residual hyperopic error. Akaishi *et al.* demonstrated an improvement of mean spherical equivalent from +1.09D to +0.26D in 16 eyes with a multifocal implant (Tecnis ZM900).[68]

Posterior capsular opacification (PCO) can result in visual disturbances secondary to loss of contrast and glare. Patients with multifocal implants are more sensitive to early PCO as compared to monofocal implants, resulting in more frequent Nd:YAG laser capsulotomies.[69,70] Additionally, the incidence of PCO is significantly higher with hydrophilic materials.[71]

However, in cases of insignificant PCO not accounting for the extent of postoperative glare caution should be taken as an unnecessary YAG capsulotomy will make subsequent IOL exchange if needed difficult.

Photic phenomenon

Haloes and glare are more often reported with an MFIOL than a monofocal implant.[72] Again, dysphotopsia is greater in refractive than diffractive models.[73]

A thorough preoperative counseling entails highlighting the incidence of postoperative glare and haloes and the subsequent resolution following neuroadaptation. Furthermore, multifocal implantation in nighttime drivers and eyes with large scotopic pupils should be carried out with extreme caution.

Conclusion

MFIOLs have undergone various developments in the past decade. The advent of trifocal and EDOF IOLs may afford superior unaided intermediate visual acuity without photic phenomenon. Additionally, lenses with aspheric profile and higher Abbe number offer superior outcomes by minimizing spherical and chromatic aberrations.

A thorough preoperative planning along with advancements in IOL technology brings us one step closer to achieving ideal postoperative outcomes offering spectacle independence and increased quality of life.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Pearce JL. Multifocal intraocular lenses. Curr Opin Ophthalmol 1996;7:2-10.
2. Knorz MC, Koch DD, Martinez-Franco C, Lorger CV. Effect of pupil size and astigmatism on contrast acuity with monofocal and bifocal intraocular lenses. J Cataract Refract Surg 1994;20:26-33.
3. Hunkeler JD, Coffman TM, Paugh J, Lang A, Smith P, Tarantino N, *et al.* Characterization of visual phenomena with the array multifocal intraocular lens. J Cataract Refract Surg 2002;28:1195-204.
4. Davison JA, Simpson MJ. History and development of the apodized diffractive intraocular lens. J Cataract Refract Surg 2006;32:849-58.
5. Voskresenskaya A, Pozdeyeva N, Pashtaev N, Batkov Y, Treushnicov V, Cherednik V, *et al.* Initial results of trifocal diffractive IOL implantation. Graefes Arch Clin Exp Ophthalmol 2010;248:1299-306.
6. de Vries NE, Webers CA, Touwslager WR, Bauer NJ, de Brabander J, Berendschot TT, *et al.* Dissatisfaction after implantation of multifocal intraocular lenses. J Cataract Refract Surg 2011;37:859-65.
7. Hoffmann PC, Hütz WW. Analysis of biometry and prevalence data for corneal astigmatism in 23,239 eyes. J Cataract Refract Surg 2010;36:1479-85.
8. Hoffer KJ. Biometry of 7,500 cataractous eyes. Am J Ophthalmol 1980;90:360-8.
9. Packer M. Effect of intraoperative aberrometry on the rate of postoperative enhancement: Retrospective study. J Cataract Refract Surg 2010;36:747-55.
10. Pepose JS. Maximizing satisfaction with presbyopia-correcting intraocular lenses: The missing links. Am J Ophthalmol 2008;146:641-8.
11. Rubenstein JB, Raciti M. Approaches to corneal astigmatism in cataract surgery. Curr Opin Ophthalmol 2013;24:30-4.
12. Mendicute J, Irigoyen C, Ruiz M, Illarramendi I, Ferrer-Blasco T, Montés-Micó R, *et al.* Toric intraocular lens versus opposite clear corneal incisions to correct astigmatism in eyes having cataract surgery. J Cataract Refract Surg 2009;35:451-8.
13. Alfonso JF, Fernández-Vega L, Montés-Micó R, Valcárcel B. Femtosecond laser for residual refractive error correction after refractive lens exchange with multifocal intraocular lens implantation. Am J Ophthalmol 2008;146:244-50.
14. Muftuoglu O, Prasher P, Chu C, Mootha VV, Verity SM, Cavanagh HD, *et al.* Laser *in situ* keratomileusis for residual refractive errors after apodized diffractive multifocal intraocular lens implantation. J Cataract Refract Surg 2009;35:1063-71.
15. Han KE, Yoon SC, Ahn JM, Nam SM, Stulting RD, Kim EK, *et al.* Evaluation of dry eye and meibomian gland dysfunction after cataract surgery. Am J Ophthalmol 2014;157:1144-500.
16. Woodward MA, Randleman JB, Stulting RD. Dissatisfaction after multifocal intraocular lens implantation. J Cataract Refract Surg 2009;35:992-7.
17. Gibbons A, Ali TK, Waren DP, Donaldson KE. Causes and correction of dissatisfaction after implantation of presbyopia-correcting intraocular lenses. Clin Ophthalmol 2016;10:1965-70.
18. Donnenfeld ED, Solomon R, Roberts CW, Wittpenn JR, McDonald MB, Perry HD, *et al.* Cyclosporine 0.05% to improve visual outcomes after multifocal intraocular lens implantation. J Cataract Refract Surg 2010;36:1095-100.
19. Tomidokoro A, Miyata K, Sakaguchi Y, Samejima T, Tokunaga T, Oshika T, *et al.* Effects of pterygium on corneal spherical power and astigmatism. Ophthalmology 2000;107:1568-71.
20. Visser N, Nuijts RM, de Vries NE, Bauer NJ. Visual outcomes and patient satisfaction after cataract surgery with toric multifocal intraocular lens implantation. J Cataract Refract Surg 2011;37:2034-42.
21. Alfonso JF, Madrid-Costa D, Poo-López A, Montés-Micó R. Visual quality after diffractive intraocular lens implantation in eyes with previous myopic laser *in situ* keratomileusis. J Cataract Refract Surg 2008;34:1848-54.
22. Alfonso JF, Fernández-Vega L, Baamonde B, Madrid-Costa D, Montés-Micó R. Visual quality after diffractive intraocular lens implantation in eyes with previous hyperopic laser *in situ* keratomileusis. J Cataract Refract Surg 2011;37:1090-6.
23. Fernández-Vega L, Madrid-Costa D, Alfonso JF, Montés-Micó R, Poo-López A. Optical and visual performance of diffractive intraocular lens implantation after myopic laser *in situ* keratomileusis. J Cataract Refract Surg 2009;35:825-32.
24. McCarthy M, Gavanski GM, Paton KE, Holland SP. Intraocular lens power calculations after myopic laser refractive surgery: A comparison of methods in 173 eyes. Ophthalmology 2011;118:940-4.
25. Wang L, Hill WE, Koch DD. Evaluation of intraocular lens power prediction methods using the American Society of Cataract and Refractive Surgeons post-keratorefractive intraocular lens power calculator. J Cataract Refract Surg 2010;36:1466-73.
26. Muftuoglu O, Dao L, Mootha VV, Verity SM, Bowman RW, Cavanagh HD, *et al.* Apodized diffractive intraocular lens implantation after laser *in situ* keratomileusis with or without subsequent excimer laser enhancement. J Cataract Refract Surg 2010;36:1815-21.
27. Khoramnia R, Auffarth GU, Rabsilber TM, Holzer MP. Implantation of a multifocal toric intraocular lens with a surface-embedded near segment after repeated LASIK treatments. J Cataract Refract Surg 2012;38:2049-52.
28. Soda M, Yaguchi S. Effect of decentration on the optical performance in multifocal intraocular lenses. Ophthalmologica 2012;227:197-204.
29. Montés-Micó R, López-Gil N, Pérez-Vives C, Bonaque S, Ferrer-Blasco T. *In vitro* optical performance of nonrotational symmetric and refractive-diffractive aspheric multifocal intraocular lenses: Impact of tilt and decentration. J Cataract Refract Surg 2012;38:1657-63.
30. Walkow T, Anders N, Pham DT, Wollensak J. Causes of severe decentration and subluxation of intraocular lenses. Graefes Arch Clin Exp Ophthalmol 1998;236:9-12.
31. Alió JL, Plaza-Puche AB, Piñero DP. Rotationally asymmetric multifocal IOL implantation with and without capsular tension ring: Refractive and visual outcomes and intraocular optical performance. J Refract Surg 2012;28:253-8.
32. Mastropasqua R, Toto L, Vecchiarino L, Falconio G, Nicola MD, Mastropasqua A, *et al.* Multifocal IOL implant with or without capsular tension ring: Study of wavefront error and visual performance. Eur J Ophthalmol 2013;23:510-7.
33. Karhanová M, Marešová K, Pluháček F, Mlčák P, Vláčil O, Sín M, *et al.* The importance of angle kappa for centration of multifocal intraocular lenses. Cesk Slov Oftalmol 2013;69:64-8.
34. Prakash G, Prakash DR, Agarwal A, Kumar DA, Agarwal A, Jacob S, *et al.* Predictive factor and kappa angle analysis for visual satisfactions in patients with multifocal IOL implantation. Eye (Lond) 2011;25:1187-93.
35. Kleiner RC, Enger C, Alexander MF, Fine SL. Contrast sensitivity in age-related macular degeneration. Arch Ophthalmol 1988;106:55-7.
36. Yoshino M, Inoue M, Kitamura N, Bissen-Miyajima H. Diffractive multifocal intraocular lens interferes with intraoperative view. Clin Ophthalmol 2010;4:467-9.
37. Mainster MA, Reichel E, Warren KA, Harrington PG. Ophthalmoscopy and vitreoretinal surgery in patients with an ARRAY refractive multifocal intraocular lens implant. Ophthalmic Surg Lasers 2002;33:74-6.

38. Gayton JL, Mackool RJ, Ernest PH, Seabolt RA, Dumont S. Implantation of multifocal intraocular lenses using a magnification strategy in cataractous eyes with age-related macular degeneration. J Cataract Refract Surg 2012;38:415-8.
39. Baumüller S, Anhalm H, Müller MF, Meyer CH. Long-term visual outcome comparison of bilateral implantation of apodised diffractive versus progressive multizonal refractive multifocal intraocular lenses after cataract extraction. Klin Monbl Augenheilkd 2013;230:791-5.
40. Xu X, Zhu MM, Zou HD. Refractive versus diffractive multifocal intraocular lenses in cataract surgery: A meta-analysis of randomized controlled trials. J Refract Surg 2014;30:634-44.
41. Cochener B, Lafuma A, Khoshnood B, Courouve L, Berdeaux G. Comparison of outcomes with multifocal intraocular lenses: A meta-analysis. Clin Ophthalmol 2011;5:45-56.
42. Carballo-Alvarez J, Vazquez-Molini JM, Sanz-Fernandez JC, Garcia-Bella J, Polo V, García-Feijoo J, *et al.* Visual outcomes after bilateral trifocal diffractive intraocular lens implantation. BMC Ophthalmol 2015;15:26.
43. Sheppard AL, Shah S, Bhatt U, Bhogal G, Wolffsohn JS. Visual outcomes and subjective experience after bilateral implantation of a new diffractive trifocal intraocular lens. J Cataract Refract Surg 2013;39:343-9.
44. Kohnen T, Titke C, Böhm M. Trifocal intraocular lens implantation to treat visual demands in various distances following lens removal. Am J Ophthalmol 2016;161:71-70.
45. Kretz FT, Müller M, Gerl M, Gerl RH, Auffarth GU. Binocular function to increase visual outcome in patients implanted with a diffractive trifocal intraocular lens. BMC Ophthalmol 2015;15:110.
46. Vryghem JC, Heireman S. Visual performance after the implantation of a new trifocal intraocular lens. Clin Ophthalmol 2013;7:1957-65.
47. Cochener B, Vryghem J, Rozot P, Lesieur G, Heireman S, Blanckaert JA, *et al.* Visual and refractive outcomes after implantation of a fully diffractive trifocal lens. Clin Ophthalmol 2012;6:1421-7.
48. Lawless M, Hodge C, Reich J, Levitz L, Bhatt UK, McAlinden C, *et al.* Visual and refractive outcomes following implantation of a new trifocal intraocular lens. Eye Vis (Lond) 2017;4:10.
49. Mojzis P, Kukuckova L, Majerova K, Liehneova K, Piñero DP. Comparative analysis of the visual performance after cataract surgery with implantation of a bifocal or trifocal diffractive IOL. J Refract Surg 2014;30:666-72.
50. Jonker SM, Bauer NJ, Makhotkina NY, Berendschot TT, van den Biggelaar FJ, Nuijts RM, *et al.* Comparison of a trifocal intraocular lens with a +3.0 D bifocal IOL: Results of a prospective randomized clinical trial. J Cataract Refract Surg 2015;41:1631-40.
51. Torun Acar B, Duman E, Simsek S. Clinical outcomes of a new diffractive trifocal intraocular lens with Enhanced Depth of Focus (EDOF). BMC Ophthalmol 2016;16:208.
52. Brown SM, Archer S, Del Monte MA. Stereopsis and binocular vision after surgery for unilateral infantile cataract. J AAPOS 1999;3:109-13.
53. Gordon RA, Donzis PB. Refractive development of the human eye. Arch Ophthalmol 1985;103:785-9.
54. Wilson ME, Trivedi RH. Choice of intraocular lens for pediatric cataract surgery: Survey of AAPOS members. J Cataract Refract Surg 2007;33:1666-8.
55. Jacobi PC, Dietlein TS, Konen W. Multifocal intraocular lens implantation in pediatric cataract surgery. Ophthalmology 2001;108:1375-80.
56. Wilson ME, Johnson WJ, Trivedi RH. Primary multifocal intraocular lens implantation for teenage-onset bilateral cataracts: Visual results a decade after surgery in 3 siblings. J AAPOS 2013;17:623-5.
57. Cristóbal JA, Remón L, Del Buey MÁ, Montés-Micó R. Multifocal intraocular lenses for unilateral cataract in children. J Cataract Refract Surg 2010;36:2035-40.
58. Lawless M, Bali SJ, Hodge C, Roberts TV, Chan C, Sutton G, *et al.* Outcomes of femtosecond laser cataract surgery with a diffractive multifocal intraocular lens. J Refract Surg 2012;28:859-64.
59. Miháltz K, Knorz MC, Alió JL, Takács AI, Kránitz K, Kovács I, *et al.* Internal aberrations and optical quality after femtosecond laser anterior capsulotomy in cataract surgery. J Refract Surg 2011;27:711-6.
60. Venter JA, Pelouskova M, Collins BM, Schallhorn SC, Hannan SJ. Visual outcomes and patient satisfaction in 9366 eyes using a refractive segmented multifocal intraocular lens. J Cataract Refract Surg 2013;39:1477-84.
61. Alfonso JF, Fernández-Vega L, Valcárcel B, Ferrer-Blasco T, Montés-Micó R. Outcomes and patient satisfaction after presbyopic bilateral lens exchange with the ResTOR IOL in emmetropic patients. J Refract Surg 2010;26:927-33.
62. Pierro L, Modorati G, Brancato R. Clinical variability in keratometry, ultrasound biometry measurements, and emmetropic intraocular lens power calculation. J Cataract Refract Surg 1991;17:91-4.
63. Erickson P. Effects of intraocular lens position errors on postoperative refractive error. J Cataract Refract Surg 1990;16:305-11.
64. Leccisotti A. Secondary procedures after presbyopic lens exchange. J Cataract Refract Surg 2004;30:1461-5.
65. Habot-Wilner Z, Sachs D, Cahane M, Alhalel A, Desatnik H, Schwalb E, *et al.* Refractive results with secondary piggyback implantation to correct pseudophakic refractive errors. J Cataract Refract Surg 2005;31:2101-3.
66. Jendritza BB, Knorz MC, Morton S. Wavefront-guided excimer laser vision correction after multifocal IOL implantation. J Refract Surg 2008;24:274-9.
67. Santhiago MR, Ventura BV, Ghanem RC, Kara-Junior N, Moraes HV Jr., Ghanem E, *et al.* Predictability and vector analysis of laser *in situ* keratomileusis for residual errors in eyes implanted with different multifocal intraocular lenses. Cornea 2016;35:1404-9.
68. Akaishi L, Bessa T, Vaz R, Canamary F, Tzelikis PF. Multifocal intraocular lens optic anteriorization capture to correct residual refractive error. J Cataract Refract Surg 2009;35:2077-83.
69. Shah VC, Russo C, Cannon R, Davidson R, Taravella MJ. Incidence of Nd: YAG capsulotomy after implantation of AcrySof multifocal and monofocal intraocular lenses: A case controlled study. J Refract Surg 2010;26:565-8.
70. Elgohary MA, Beckingsale AB. Effect of posterior capsular opacification on visual function in patients with monofocal and multifocal intraocular lenses. Eye (Lond) 2008;22:613-9.
71. Gauthier L, Lafuma A, Laurendeau C, Berdeaux G. Neodymium: YAG laser rates after bilateral implantation of hydrophobic or hydrophilic multifocal intraocular lenses: Twenty-four month retrospective comparative study. J Cataract Refract Surg 2010;36:1195-200.
72. de Silva SR, Evans JR, Kirthi V, Ziaei M, Leyland M. Multifocal versus monofocal intraocular lenses after cataract extraction. Cochrane Database Syst Rev 2016;12:CD003169.
73. Cillino S, Casuccio A, Di Pace F, Morreale R, Pillitteri F, Cillino G, *et al.* One-year outcomes with new-generation multifocal intraocular lenses. Ophthalmology 2008;115:1508-16.