Received: 22 June 2023 | Revised: 4 October 2023 | Accepted: 8 October 2023

DOI: 10.1111/ceo.14315

ORIGINAL ARTICLE - CLINICAL SCIENCE

Clinical & Experimental Ophthalmology WILEY

Unilateral intraindividual comparison and bilateral performance of a monofocal spherical and diffractive extended depth of field intraocular lens mix-and-match approach

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Funding information
ESCRS Peter Barry Fellowship Award

Abstract

Background: To evaluate the intraindividual visual performance of a spherical and extended depth of field (EDOF) IOL used in a mix-and-match approach.

Methods: Single centre (tertiary care centre), retrospective consecutive case series. Included patients had uneventful cataract surgery with implantation of a spherical monofocal IOL (CT Spheris 204) in the dominant eye and a diffractive EDOF IOL (AT LARA 829) in the non-dominant eye. Monocular and binocular defocus curves and visual acuity at various distances were assessed. In addition, binocular reading speed, contrast sensitivity, and patient satisfaction using QOV, Catquest 9SF, and glare/halo questionnaires are reported.

Results: A total of 29 patients (58 eyes) were included. We observed significant intra-individual differences for monocular DCIVA, DCNVA, UIVA, and UNVA. There were no differences in monocular BCDVA or UDVA. The monocular defocus curves for the two IOLs significantly differed at defocus steps between −1.0 and −3.5 D. 93.10% of patients reported they would opt for the same combination of IOLs.

Conclusion: Excellent uncorrected and corrected distance visual acuity was demonstrated in both groups. The mix-and-match approach described in this study yielded good intermediate vision and improved near vision with high-patient satisfaction.

KEYWORDS

diffractive optics IOL, EDOF, hybrid monovision, mix and match, spherical IOL

1 | INTRODUCTION

One of the main challenges in presbyopia correcting intraocular lens (IOL) surgery is finding the right balance between depth of field and unwanted side effects of multifocality. Although diffractive multifocal (MFIOL), trifocal (TF-IOLs), and extended depth of field (EDOF-IOLs) IOLs provide improved vision over a range of distances, they may also be associated with photic phenomena such as glare, reduced contrast sensitivity, and dysphotopsias. For many patients, despite excellent objective visual acuity outcomes with these diffractive optics IOLs (DO-IOLs), the aforementioned unwanted phenomena can cause significant patient dissatisfaction, and the need for additional surgery (e.g., IOL exchange, etc.).[1]

While monovision options may avoid photic phenomena, disadvantages, such as a loss of binocular summation, asthenopia, aniseikonia, loss of stereopsis, and dissatisfaction with defocus in the myopic eye, may limit this approach in many patients.[2,3] In 2011, Iida et al. reported a new mix-and-match technique called "hybrid monovision" for reducing presbyopia after cataract surgery.[4] This approach combines a monofocal IOL in the dominant eye with a MFIOL in the non-dominant eye. This synergistic approach aims to combine the strengths of each IOL to minimise the potential limitations of each.[5] Specifically, a hybrid monovision approach may help reduce photic phenomena (compared to bilateral DO-IOL implantation), improve spectacle independence (compared to bilateral monofocal IOL implantation), and maintain distance stereoacuity (compared to monofocal IOL monovision techniques). This approach also offers a solution to patients that received previous unilateral cataract surgery with monofocal IOLs (in the dominant eye) and desire more spectacle independence after the second eye cataract surgery. Furthermore, it allows for mix-and-matching scenarios in patients where anatomic features allow for DO-IOL implantation in one eye but are not ideal candidates in the second eye. While hybrid monovision with MFIOLs is reported in the literature, results of hybrid monovision using an EDOF IOL are scarce.

We sought to evaluate hybrid monovision using a mix-and-match approach with a monofocal spherical IOL and a diffractive-optics aspheric EDOF IOL. Herein, bilateral performance, in term of distance, intermediate and near visual acuity (corrected and uncorrected), contrast sensitivity, reading speed, and patient satisfaction with a monofocal/EDOF hybrid monovision is described.

2 | METHODS

This retrospective study was performed in accordance with the local ethics committee (EK 1268/2022) and the ethical standards of the Helsinki Declaration of 1964 and its current revisions. The consecutive case series included all patients who underwent uncomplicated bilateral cataract surgery between November 2019 and January 2021 using a hybrid monovision technique (monofocal IOL in the dominant eye; EDOF IOL in the contralateral eye) at the study institution, and a postoperative refraction performed 1, 3, and 6 months after the second eye surgery. No patients who received this combination of IOLs over the study period were excluded from the analysis. The monofocal spherical IOL used was the Zeiss CT Spheris 204 (Carl Zeiss Meditec AG, Oberkochen, Germany), and the EDOF-IOL used was the Zeiss AT LARA 829. Both eyes were targeted for emmetropia.

Established patient selection criteria at the study location to qualify for the mix-and-match approach was an expected postoperative corrected distance visual acuity (CDVA) ≥ 0.2logMAR, while exclusion criteria were preoperative corneal astigmatism greater than 1.0 diopter (D), amblyopia or reduced expected postoperative visual acuity, strabismus, a history of ophthalmic and refractive surgery, and ocular disease other than cataract. All patients had preoperative biometry [IOLMaster 700 (Carl Zeiss Meditec AG)], and tomography [Pentacam (Oculus, Wetzlar, Germany)], and underwent cataract surgery by phacoemulsification through superior clear corneal incisions.

Quality control measures in our clinic for all new IOL combinations include, as a standard of care, subjective manifest refraction and visual acuity (VA) testing performed by an experienced optometrist or clinician 1, 3, and 6 months after surgery at a lane distance of 4 m, 80 cm, and 40 cm using ETDRS optotype charts designed for the three respective distances. Monocular and binocular best corrected distance visual acuity (BCDVA), distance corrected intermediate visual acuity (DCIVA), distance corrected near visual acuity (DCNVA) were gathered. Uncorrected distance, intermediate, and near visual acuity (UDVA, UIVA, UNVA) were acquired in the same manner. The patient was then asked to choose the intermediate and near distance with the best VA. These distances were measured, and VA testing was repeated at these distances. One month postoperatively, distance-corrected binocular reading speed was ascertained using the IREST test,[6] and contrast sensitivity testing was performed under photopic conditions using a bilateral Pelli Robson Test. Unilateral and bilateral distance-corrected defocus curves from +1.0 to −4.0 D were performed 6 months after surgery in 0.50 D increments.

2.1 | Photic phenomena

The Halo and Glare simulator (ViSU-L GmbH, Hamburg, Germany) was used to subjectively categorise the patients' daily-life photic phenomena 3 months after surgery. The patient can choose between three different forms of halo and starburst. Afterwards, the intensity and size of halo and glare phenomena can each be adjusted on a scale of 0 to 100. Six months after surgery, patients were asked to fill out Catquest-9SF tests[7] and adapted QOV questionnaires.[8–10]

Data were analysed using Microsoft Excel (v.16.12, Microsoft Corp) and SPSS software (SPSS V 24.0; IBM, USA). Descriptive statistics are provided via tables. The Shapiro–Wilk-Test was used to determine the distribution normality of metric variables. Visual acuity at various defocus steps and at various distances was compared using either a Wilcoxon signed rank (paired) or a Wilcoxon rank sum (unpaired) test. When needed, Bonferroni post-hoc correction was applied to counteract the multiple comparisons problem. The level of significance was set to $p < 0.05$.

3 | RESULTS

Twenty-nine patients met criteria for inclusion in the study. There were no intra- or postoperative complications. There were 15 females and 14 males. Mean age at IOL implantation was 67 ± 9.70 years. Preoperative pupil size, IOL power, and postoperative subjective refraction data are displayed in Table 1.

3.1 | Visual acuity

Table 2 depicts the monocular and binocular distance corrected and uncorrected visual acuities for distance (BCDVA and UDVA), intermediate (DCIVA and UIVA) and near (DCNVA and UNVA). Differences were observed between the spherical monofocal and EDOF IOL for DCIVA ($p < 0.001$), UIVA ($p < 0.001$), DCNVA ($p < 0.001$), and UNVA ($p < 0.001$). There were no significant differences in monocular BCDVA or UDVA.

Binocular summation increases VA; therefore, monocular VA of each eye was also compared to binocular VA. For the spherical IOL, differences were noted between monocular and binocular VA for DCNVA ($p < 0.001$) and DCIVA ($p < 0.001$). For the EDOF-IOL, differences were observed between monocular and binocular VA for BCDVA only ($p = 0.004$).

Figure 1 shows monocular and binocular distance-corrected defocus curves. Compared to the monofocal IOL, the EDOF IOL offered enhanced visual acuity for a defocus of −1.0 D and larger magnitudes of negative defocus. However, when analysing binocular results, a synergistic effect from binocular summation is observed with improved visual acuity across all defocus increments. As most of the data were not normally distributed, SD was not shown. Accompanying boxplots show the median in the form of a line, the mean in the form of a cross, the interquartile range as a box, outliers (defined as values with more than one and a half times the interquartile range) as dots, and minimum-maximum within the outlier limit as whiskers.

Between IOLs, significant differences were observed for defocus steps of −1.0 D ($p = 0.019$), −1.5 D ($p < 0.001$), −2.0 D ($p < 0.001$), −2.5 D ($p = 0.003$), −3.0 D ($p = 0.022$), and − 3.5 D ($p = 0.031$).

The binocular distance-corrected mean reading speed at 60 cm distance was 144.15 ± 39.24 words/min (median 150.78 words/min; min 65 words/min; max 203 words/min). In binocular photopic contrast sensitivity testing, patients recognised an average of 36.14 ± 1.92 optotypes (min 32; max 42) corresponding to a mean logarithmic contrast sensitivity of 2.24 (min 3.16; max 1.12).

Table 3 displays answers of the Cat-Quest 9-SF questionnaire. Results of all questions in the QOV questionnaire are listed in Table 4. Notably, 93.10% of the patients would chose the same hybrid monovision mix-and-match approach again.

TABLE 1 Pupil size, IOL power, and postoperative subjective refraction data.

	Monofocal IOL Mean ± SD (min, max)	EDOF IOL Mean ± SD (min, max)
IOL power (D)	20.97 ± 1.78 (17, 24)	20.96 ± 1.74 (17, 24)
Pupil size (mm)	3.74 ± 0.94 (2.31, 6.07)	3.65 ± 0.90 (2.35, 5.85)
SEQ 3 months postOP (D)	0.07 ± 0.45 (−1.0, 1.0)	−0.06 ± 0.38 (−0.88, 0.63)
SEQ 6 months postOP (D)	0.07 ± 0.50 (−0.88, 1.25)	−0.07 ± 0.62 (−1.63, 1.0)
Astigmatism magnitude 3 months postOP (D)	0.68 ± 0.36 (0, 1.50)	0.79 ± 0.50 (0.25, 2.50)
Astigmatism magnitude 6 months postOP (D)	0.66 ± 0.47 (0, 2.0)	0.71 ± 0.44 (0, 2.0)
DEQ 3 months postOP (D)	−0.29 ± 0.50 (−1.75, 0.25)	−0.42 ± 0.40 (−1.25, 0.25)
DEQ 6 months postOP (D)	−0.18 ± 0.60 (−1.50, 1.75)	−0.44 ± 0.67 (−2.00, 0.75)

Note: Intraocular lens power, preoperative pupil size, and postoperative subjective refraction data of spherical equivalent, astigmatism, and defocus equivalent.
Abbreviations: D, diopters; EDOF, extended depth-of-field; IOL, intraocular lens; SD, standard deviation; SEQ, spherical equivalent; DEQ, defocus equivalent.

TABLE 2 Visual acuity results after 3 months.

	Eye	Mean	SD	Min	Max
BCDVA	Monofocal	−0.11	0.11	−0.30	0.30
	EDOF	−0.08	0.10	−0.30	0.20
	Binocular	−0.14	0.10	−0.30	0.10
DCIVA	Monofocal	0.20	0.13	−0.10	0.40
	EDOF	0.00	0.12	−0.20	0.30
	Binocular	−0.04	0.13	−0.30	0.20
DCNVA	Monofocal	0.46	0.19	0.10	1.00
	EDOF	0.29	0.12	0.10	0.60
	Binocular	0.23	0.13	0.00	0.50
UDVA	Monofocal	0.01	0.15	−0.20	0.50
	EDOF	0.05	0.11	−0.10	0.30
UIVA	Monofocal	0.21	0.18	−0.10	0.60
	EDOF	0.00	0.12	−0.20	0.30
UNVA	Monofocal	0.51	0.21	0.20	0.80
	EDOF	0.23	0.14	0.00	0.70
Preferred distance for UIVA (cm)	Monofocal	73.81	5.92	66	86.50
	EDOF	70.89	5.53	62.80	80
Preferred distance for DCIVA (cm)	Monofocal	75.50	5.18	64.0	86.50
	EDOF	73.02	6.61	58.50	90.0
	Binocular	69.38	15.03	1.25	96.0
Preferred distance for UNVA (cm)	Monofocal	38.60	2.40	32.0	40.0
	EDOF	38.91	2.01	34.0	40.0
Preferred distance for DCNVA (cm)	Monofocal	39.10	1.51	35	40
	EDOF	39.07	1.82	33	40
	Binocular	38.80	2.32	30	40

Note: Visual acuity results after 3 months. Results are presented in logMAR.
Abbreviations: BCDVA, best corrected distance visual acuity; DCIVA, distance corrected intermediate visual acuity; DCNVA, distance corrected near visual acuity; SD, standard deviation; UDVA, uncorrected distance visual acuity; UIVA, uncorrected intermediate visual acuity; UNVA, uncorrected near visual acuity.

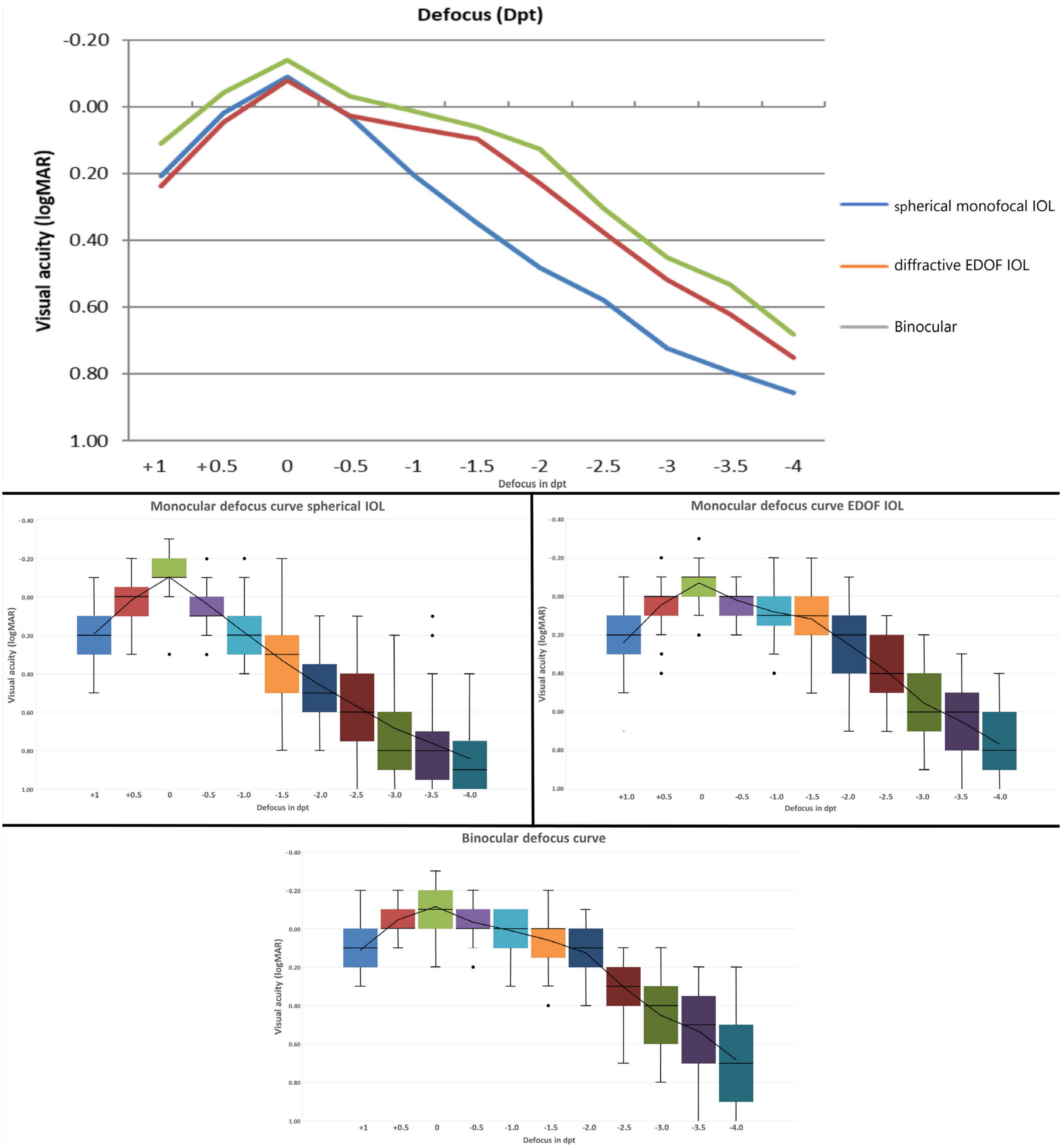

FIGURE 1 Defocus curves of the monocular and binocular performances of the monofocal spherical intraocular lens (IOL), and the extended depth of field IOL. The boxplots show the median in the form of a straight line, the mean in the form of a cross (connected by a line), the interquartile range as a box, outliers (defined as values with more than one and a half times the interquartile range) as dots and minimum and maximum within the outlier limit as whiskers.

Subjectively, using the Halo and Glare simulator, eight patients experienced glare and rated mean glare size as 24.75 ± 18.87 and mean glare intensity as 46.13 ± 23.44. Furthermore, 12 patients experienced halos. Mean halo size was rated as 39.17 ± 21.95 and mean halo intensity as 48.75 ± 19.17 (Figure 2).

TABLE 3 Catquest 9-SF Questionnaire.

	Very dissatisfied	Fairly dissatisfied	Fairly satisfied	Very satisfied
Are you satisfied or dissatisfied with your sight at present?	0	10.34	24.14	65.52
	Yes, very great difficulty	Yes, great difficulty	Yes, some difficulty	No, no difficulty
Do you find your sight at present in some way causes difficulty in your everyday life?	0	6.90	31.03	62.07
Do you have difficulty with the following activities because of your sight:				
Reading text in the daily paper	6.90	6.90	34.48	51.72
Recognise the faces of people you come across	0	0	6.90	93.10
See prices when shopping	0	6.90	20.69	71.41
Seeing to walk on uneven ground	0	0	10.34	89.66
See to do handwork/woodworking, etc.	0	6.90	34.48	58.62
Reading text on TV	0	0	34.48	65.52
See to carry on activity/hobby you are interested in	0	0	10.34	89.66

Note: Catquest 9-SF questionnaire results—displayed are the percentages of patients that chose the respective answers.

4 | DISCUSSION

Given the number of available IOL types for patients desiring presbyopia correction, surgeons are challenged to find IOL options that provide an optimal combination of spectacle independence, high contrast sensitivity, and minimal photic phenomena. While bilateral presbyopia-correcting IOL implantation results have been reported extensively in the literature, there has been a recent interest in utilising "mix-and-match" approaches for selected patient populations, especially in unilateral pseudophakic patients with an existing monofocal IOL. Several presbyopia correction approaches may be considered for these patients, including multifocal monovision, blended vision, and hybrid monovision options. We present the results for a distinctive group of patients who seek enhanced spectacle independence following unilateral monofocal IOL implantation. Our study reports several unique findings that were not reported before. For one, this is the first study to analyse the combination of a spherical IOL and an EDOF IOL, offering insights into IOL choices for patients that already received implantation of a monofocal IOL in one eye but seek more depth of field after surgery on the second eye. Furthermore, this is the first study to report defocus curves of the CT Spheris 204 and directly compare the defocus curve of a spherical IOL to an EDOF IOL in an intraindividual comparison.

Mix-and-match strategies offer an opportunity for direct comparison in terms of the visual performance of an IOL. This study primarily investigated the depth of field and visual acuity of the two IOLs used: a monofocal spherical IOL and an EDOF-IOL utilising diffractive optics. While there is some discussion on how to classify EDOF IOLs, at the current point in time, the AT LARA is classified as EDOF IOL according to ISO DIS 11979-7 which defines IOL by the achievable foci (distance & intermediate) and not the optical design that achieves these foci; it is not a focus of this study to challenge established classification of the AT LARA 829 as either diffractive EDOF IOL or diffractive multifocal IOL.

In our mix-and-match approach, we opted for a spherical IOL in the dominant eye. We eschewed an aspheric IOL because we surmised that positive spherical aberration supplied by a spherical IOL could have favourable effects on depth of field and intermediate vision while maintaining distance visual acuity and therefore increase binocular summation over a larger range of vision.[11,12] Thus, a spherical IOL may be paired with an EDOF-IOL, as the latter IOL provides an even greater depth of field. While spherical IOLs may have fallen out of favour for routine cataract surgery in modern practice, these properties mentioned above merit (re)consideration for their utility for presbyopia correction in conjunction with currently-available IOLs. Thus, spherical IOLs may confer advantages when paired with EDOF-IOLs, as the latter IOL offers an even greater depth of field by offering the advantage of enabling binocular summation over a slightly larger range.

TABLE 4 QOV questionnaire.

	Never	Occasionally	Quite often	Very often	
How often do you experience glare?	31.03	65.52	0	3.45	
How often do you experience halos?	37.93	41.38	13.79	6.9	
How often do you experience starbursts?	39.13	56.52	4.35	0	
How often do you experience focusing difficulties?	33.33	52.88	9.52	4.76	
	Not at all	**Mild**	**Moderate**	**Severe**	
How severe is the glare?	34.48	34.48	24.14	6.90	
How severe are the halos?	37.50	41.67	12.50	8.33	
How severe are the starbursts?	27.27	59.09	9.09	4.55	
How severe are the focusing difficulties?	59.09	31.82	4.55	4.55	
	Not at all	**A little**	**Quite**	**Very**	
How bothersome is the glare?	37.93	34.48	20.69	6.90	
How bothersome are the halos?	30.43	52.17	17.39	0	
How bothersome are the starbursts?	31.82	54.55	9.09	4.55	
How bothersome are the focusing difficulties?	60	20	15	5	
	Yes	**No**			
If you had to choose again, would you pick the same IOL combination again?	93.10	6.9			
	Yes	**No**			
Did the surgery offer you spectacle indepency (distance)?	75.86	24.14			
Did the surgery offer you spectacle indepency (intermediate)?	79.31	20.69			
Did the surgery offer you spectacle indepency (near)?	48.28	51.27			
	Never	**Seldom**	**Half of the time**	**Most of the time**	**Always**
How often do you wear glasses (distance)?	75	8.33	4.17	8.33	8.33
How often do you wear glasses (intermediate)?	70.83	8.33	8.33	16.67	8.33
How often do you wear glasses (near)?	29.17	25	16.67	8.33	16.67

Note: Displayed is the percentage of answers for the various subcategories of the QOV questionnaire.

EDOF-IOLs have gained attention among researchers recently. Among the most interesting points for us was distance visual acuity. Binocular summation is reduced with increasing defocus in patients that receive monovision with two monofocal IOLs. A scenario that gives DOF without compromising binocular distance visual acuity offers merits. As expected, binocular BCDVA was significantly better than monocular BCDVA with each IOL. While we found no significant differences in BCDVA and UDVA between both IOLs, some authors have reported that EDOF IOLs can provide similar or even better UDVA outcomes than monofocal IOLs, while providing excellent UIVA and UNVA.[13–15] For example, Pedrotti et al. reported 90% of patients gained a mean UDVA of 0.0 logMAR or better, mean UIVA of 0.05 + 0.09 logMAR and mean UNVA of 0.18 + 0.09 logMAR, which is similar to our results.[16] The EDOF IOL seems to offer no compromise in DVA in photopic conditions. Due to the retrospective nature of our study, we could not verify if the same is true in mesopic conditions, a possible topic for future research.

Our intraindividual scenario allows a direct comparison of the DOF of both IOLs. The American Academy of Ophthalmology Task Force Consensus Statement for EDOF IOLs states that the monocular depth of field for the EDOF IOL needs to be at least 0.5 D greater than the depth of field for the monofocal IOL controls at logMAR 0.2.[17] As shown in Figure 1, intraindividual comparison of the two studied IOLs demonstrated a significantly higher VA for all defocus steps from −1.0 D to −4.0 D with the AT LARA providing a benefit of more than 0.50 D of DOF at logMAR 0.2 compared to the CT

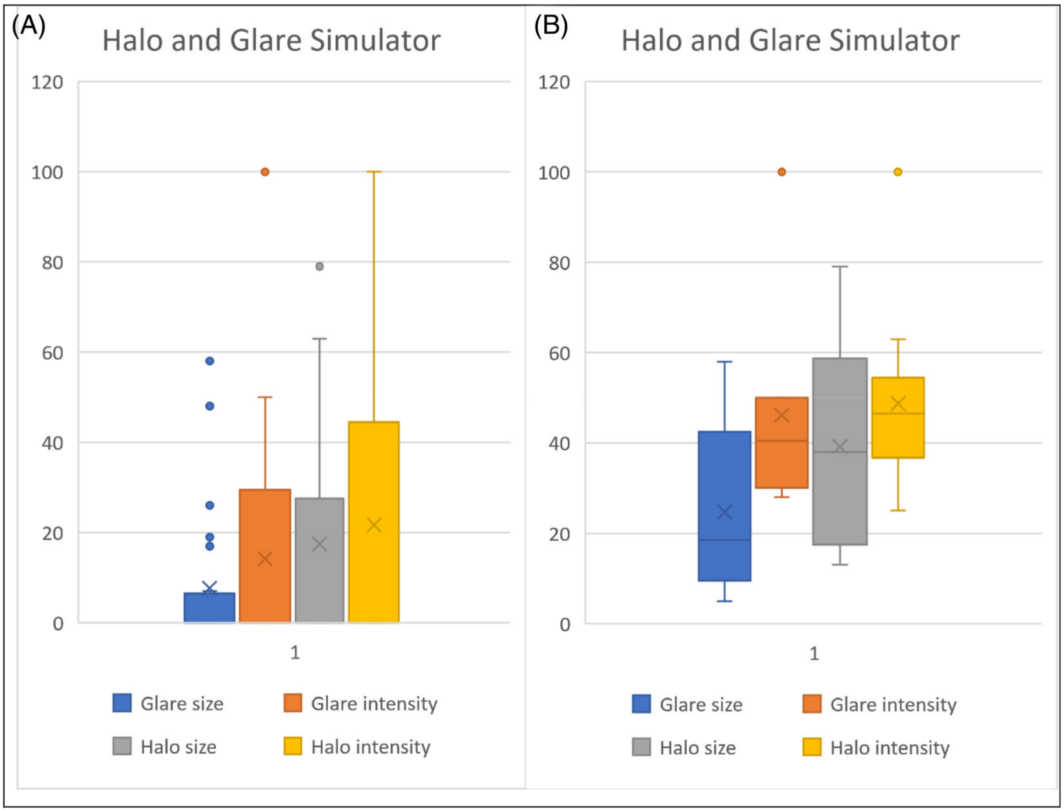

FIGURE 2 Glare and halo size and intensity for all patients (Figure 2A on the left side) and only for patients experiencing glare or halos (Figure 2B on the right side).

Spheris. The spherical IOL provided a VA of 0.3logMAR up to a defocus of −1.0 D, whereas the EDOF IOL was able to provide a VA of 0.3 logMAR up to −2.50 dpt. A significantly better DCIVA, DCNVA, UIVA, and UNVA was observed for the EDOF IOL. Notably, there was no difference in postoperative subjective SEQ of both IOLs—hence, both IOLs seem to offer predictable results. Reinhard et al. reported two additional focus planes at far-intermediate and intermediate distances for the AT LARA829 and found binocular defocus curves of the AT LARA to be comparable to the established TECNIS Symfony EDOF IOL (Johnson & Johnson) with a slightly superior performance of the LARA in monocular defocus curves.[18] Reinhard et al. and Tahmaz et al. both reported an improved depth of field for either a diffractive or non diffractive EDOF IOL compared to aspheric monofocal IOLS.[18,19] Rodov et al. reported a significant superiority of EDOF IOLs compared to a monofocal group for depth of field, but added that monofocals used in a monovision approach can provide good depth of field and UDVA.[20] Jeon et al. compared a diffractive EDOF IOL (TECNIS Symfony) and a Monofocal plus IOL (Tecnis Eyhance) and found the former offered improved near visual acuity, and the latter offered better optical quality.[21] A mix-and-match approach using an enhanced monofocal and conventional monofocal IOL may be a topic for future study.

Our theorised advantage of binocular summation is not only interesting for DVA, but also for intermediate and near distances. Regarding binocular VA without EDOF defocus, we observed that our mix-and-match approach resulted in higher visual acuity across all areas of the defocus curve compared to monocular visual acuity with a monofocal or EDOF alone. As expected, lower visual acuity was observed at near vision targets; however, binocular DCNVA was 0.24 logMAR, allowing useful visual function for everyday near vision tasks. However, we also observed favourable results at distance and intermediate, reaching −0.15 and −0.04 logMAR, respectively. Iida et al. reported the results of their hybrid monovision approach with a monofocal IOL and TFIOL.[4] We sought to further refine this approach by replacing the TFIOL with an EDOF-IOL to give less difference in the area under the curve (related to defocus curve) between both eyes and fewer photic phenomena. Our patients' acceptance of this approach further confirms Iida et al.'s results and suggests that a mix-and-match approach with diffractive optics in the non-dominant eye can be tolerated and beneficial. Our objective VA results, combined with a high degree of subjective satisfaction

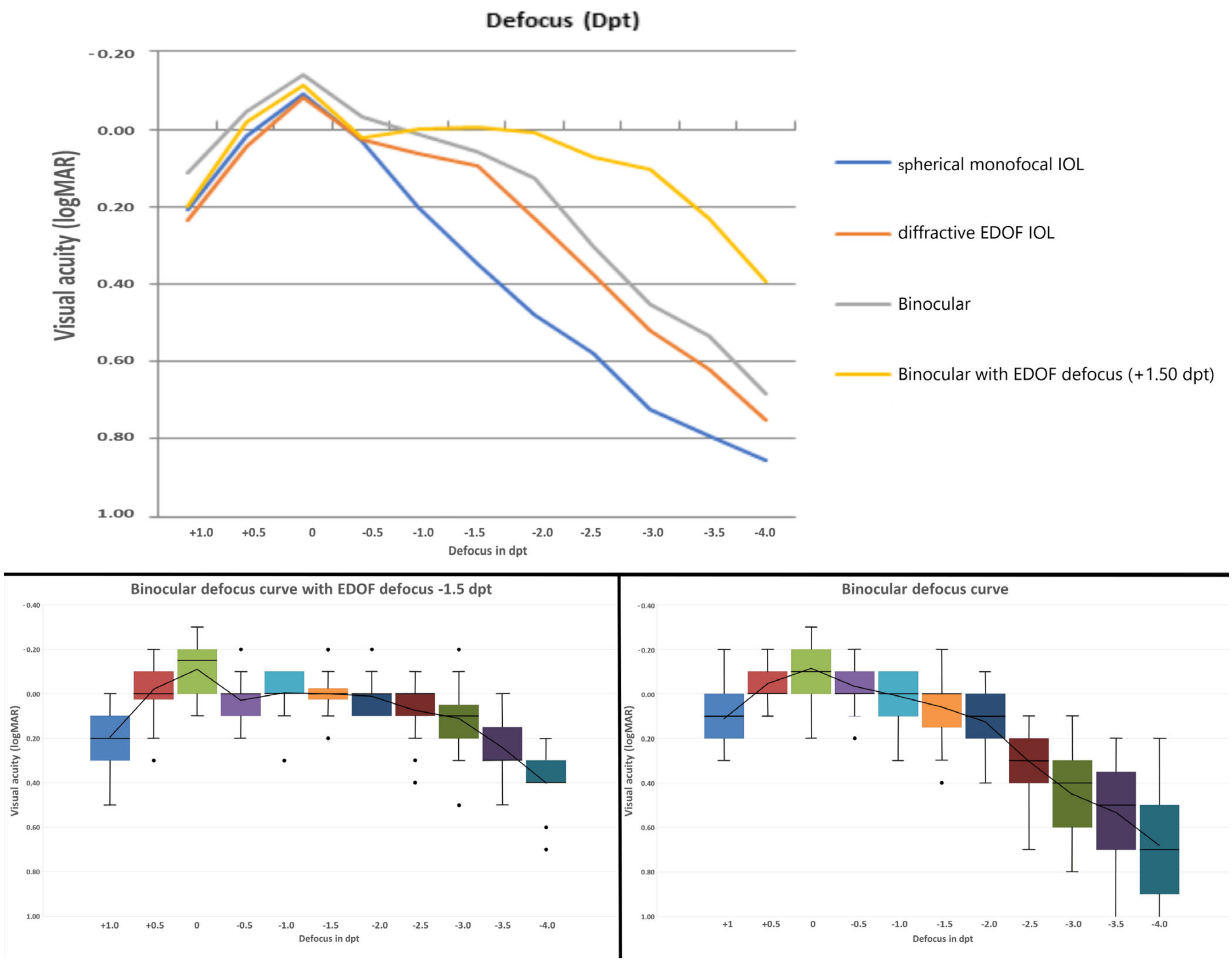

FIGURE 3 Simulation of a surgically intendend monovision with the EDOF IOL eye aimed at −1.50 D. There were statistically significant differences for defocus steps of −0.5 D ($p = 0.002$), −2.0 D ($p = 0.004$), −2.5 D ($p = 0.001$), −3.0 D ($p < 0.001$), −3.5 D ($p = 0.001$), −4.0 D ($p = 0.001$). There were no significant differences for −1.0 and −1.50 D of defocus.

noted on the postoperative questionnaires, suggest that the binocular performance of this IOL combination provides excellent acuity with minimal bothersome aberrations, similar to other reports.[22] Regarding photic phenomena, other authors have reported that patients experience fewer unwanted visual disturbances when implanted with EDOF-IOLs than with MF-IOLs.[9,23] In one study examining bilateral EDOF IOLs, there was no increase in photic phenomena as the degree of monovision increased.[24] Due to this study's retrospective nature and the intraindividual comparison that will inevitably influence any questionnaire regarding monocular function given daily binocular experience, we could not rate differences in these parameters between both IOLs. We can, therefore, only rate the binocular experience of our approach.

It is never easy to interpret questionnaire results for different premium IOLs, as results in studies with few participants are heavily influenced by subjective criteria, if and how much patients paid for IOLs, where expectations were directed before surgery, and if lower-order and higher-order aberrations are present. How lower-order aberrations interfere with our study results can be seen by 24.14% reporting spectacle dependence for distance. This correlates perfectly with current thresholds of predictive accuracy for IOL calculation in regards to SEQ (70%–80% within ±0.5 D) and astigmatic vectors (around 60% within ±0.5 D). The realistic goal of our IOL combination was spectacle independence in intermediate distances, which 79.31% actually achieved, while almost 50% even reported spectacle independency in near distances. Interestingly, only 8% of patients reported halo phenomena. They were observed more often than other photic phenomena. Yet, glare seemed to be the most bothersome phenomenon, followed by halos, while starbursts were no problem. Glare is to be expected the most when coupling a spherical IOL and an aspheric but aberration neutral DO IOL. Yet, the mix should still amount to less photic phenomena than two trifocal IOLs that create larger Halos. We reached high satisfaction in both questionnaires.

We also sought a theoretic answer to the question of what a surgically intended (hybrid) monovision of the study IOLs could offer. For this task, we simulated that the EDOF IOL eye was aimed at −1.50 D by adding a unilateral defocus to all steps of the distance-corrected defocus curve (Figure 3).

In our binocular defocus curve for this mix-and-match hybrid monovision, we noticed a spike at −0.5 D that reduced binocular VA to the level of both monocofal defocus curves. This reduction suggests that the defocus chosen for the EDOF IOL monovision was too much and interfered with binocular summation at distance, reducing some of the merits of our mix-and-match approach, even though near and intermediate VA clearly benefited. A defocus of 1.0 D or 0.75 D might lead to better results while still offering good VA at intermediate and near distances. This may be useful for a patient who is pseudophakic in one eye with a monofocal IOL and is dissatisfied and seeks more DOF than our mix-and-match scenario with both eyes aimed at emmetropia can offer. One adverse effect of conventional monovision is reduced stereopsis, especially with increasing degrees of anisometropia.[25] A potential advantage of our hybrid monovision approach is the reduction of anisometropia across all refractions, causing more overlap in defocus curves, especially if a defocus of 0.75 D to 1.0 D is chosen, hence we offer a larger range for binocular summation of both eyes. This approach further improves the degree of stereopsis compared to conventional monovision. Our current study did not evaluate the degree of stereopsis, though this is a direction for future research.

The strength of our study includes reporting objective visual acuity and subjective visual function results in a direct intraindividual comparison of a novel hybrid monovision approach. However, our study has some important limitations. First, the retrospective nature of this study did not allow for more rigorous testing of contrast sensitivity at various spatial frequencies and brightness levels to compare both IOLs directly. Second, photic phenomena and questionnaires could only be reported for a binocular experience due to the intraindividual design. They were not distance-corrected and might therefore be impacted by lower-order aberrations. Third, the hybrid monovision with EDOF-IOL defocus testing was only simulated in defocus curves and not directly implanted.

In conclusion, the described mix-and-match hybrid monovision approach utilising a spherical IOL and EDOF-IOL offers surgeons an efficacious strategy to provide patients with favourable visual acuity at all distances with minimal deleterious photic phenomena. Future studies, including testing different models of spherical and EDOF-IOLs, may provide further confirmation of our findings.

FUNDING INFORMATION

Dr. Wendelstein was supported by an “ESCRS Peter Barry Fellowship Award” for the publication and its content. All other authors received no financial support for the research, authorship, and/or publication of this article.

CONFLICT OF INTEREST STATEMENT

Wendelstein reports personal fees from Carl Zeiss Meditec AG, Alcon Surgical, Rayner Surgical, and Johnson & Johnson Vision outside of the submitted work. He is supported by an “ESCRS Peter Barry Fellowship Award.” Riaz reports consulting fees from Ambrx Pharmaceuticals and Immunogen, and personal fees from Bausch and Lomb and CorneaGen outside of the submitted work. Pantanelli receives research support from Alcon, Bausch and Lomb, and Carl Zeiss Meditec outside of the submitted work. He is also a consultant for Bausch and Lomb, Carl Zeiss Meditec, and Hoya Surgical Optics outside of the submitted work. Bolz reports personal fees from Carl Zeiss Meditec AG outside of the submitted work. He has no consulting function in any of the aforementioned companies. Seiler reports personal fees and consultant functions from Glaucos, Schwind and Ziemer outside of the submitted work. Prof. Kohnen reports personal fees as consultant and for research for Alcon/Novartis, J&J, Lensgen, Oculentis, Oculus, Presbia, Schwind, Zeiss. Furthermore, he reports personal fees as consultant for Allergan, Bausch & Lomb, Geuder, Med Update, Santen, Staar, Thieme, Ziemer. There are no conflicts of interest for the other authors.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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How to cite this article: Wendelstein JA, Casazza M, Reifeltshammer S, et al. Unilateral intraindividual comparison and bilateral performance of a monofocal spherical and diffractive extended depth of field intraocular lens mix-and-match approach. *Clin Exp Ophthalmol*. 2023;1-11. doi:10.1111/ceo.14315