Open Access

Visual Performance at All Distances and Patient Satisfaction With a New Aspheric Inverted Meniscus Intraocular Lens

José M. Marín, MD, PhD; Lucía Hervella, PhD; Eloy Villegas, PhD; Consuelo Robles, PhD; Encarna Alcón, MSc; Inés Yago, MD, PhD; Pablo Artal, PhD

ABSTRACT

PURPOSE: To evaluate visual performance, spectacle independence, and quality of vision of new intraocular lenses (IOLs) for presbyopia correction with an aspheric inverted meniscus optical design (ArtIOLs; Voptica SL) in patients undergoing bilateral cataract surgery.

METHODS: In this prospective study, 60 eyes from 30 patients implanted bilaterally with Art40 and Art70 IOLs were included. These new IOLs were designed with an inverted meniscus shape to improve the peripheral performance and with aspheric surfaces to induce different amounts of negative spherical aberration in each IOL model. Distance-corrected and uncorrected through-focus visual acuities and contrast sensitivity were measured 1 to 3 months after surgery. Twenty-eight patients answered Patient Reported Spectacle Independence (PRSIQ) and Quality of Vision (QoV) questionnaires.

RESULTS: Mean monocular (Art40 and Art70) and binocular (Art40/70) corrected distance visual acuities (CDVA) were zero logMAR (20/20). Binocular uncorrected distance visual acuity (UDVA) at far, intermediate (66 cm), and near (40 cm) distances was 0.00 ± 0.01, 0.01 ± 0.03, and 0.09 ± 0.09 logMAR, respectively. Spectacle independence was achieved by 24 (85.7%) patients for far and intermediate vision and 20 patients (71.4%) for near vision. The number of patients never reporting experiencing glare, halos, and starbursts was 28, 27, and 26 (100%, 96.4%, and 92.9%), respectively.

CONCLUSIONS: The binocular combination of two ArtIOLs models (Art40 and Art70) significantly extended the depth of focus up to at least 40 cm. This combination resulted in a full range of vision with a high level of spectacle independence and without the compromise of halos or dysphotopsias.

[*J Refract Surg*. 2023;39(9):582-588.]

Intraocular lens (IOL) designs are constantly evolving to improve patients' vision needs. Spectacle independence is repeatedly a request by patients undergoing cataract surgery and, consequently, multifocal IOLs are highly demanded. Monovision is used by some surgeons to improve vision at different distances,[1] but its success depends on the ability of each patient to get used to a considerable amount of monocular defocus. Currently, there is a wide range of different types of IOLs to consider, depending on patients' desire to see at different distances and their tolerance for potential visual disturbances. Trifocal diffractive multifocal IOLs are designed to achieve good visual acuity at three distances (far, intermediate, and near). However, they are associated with some disturbing phenomena,[2] such as halos and glare, and loss of contrast sensitivity, es-

From Laboratorio de Optica, Departamento de Física, Universidad de Murcia, Murcia, Spain (JMM, EV, PA); Oftalvist Clinic, Murcia, Spain (JMM, EA); Oftalmología, Hospital Universitario Virgen de la Arrixaca, Murcia, Spain (JMM, IY); and Voptica SL, Murcia, Spain (LH, CR).

Submitted: May 22, 2023; Accepted: August 2, 2023

Supported by Agencia Estatal de Investigación (Grant No. PID2019-105684RB-I00/AEI/10.13039/501100011033).

Disclosure: Drs. Villegas and Artal hold patents on the meniscus intraocular lenses. Drs. Robles and Hervella are employees of Voptica SL. The remaining authors have no financial or proprietary interest in the materials presented herein.

Correspondence: José M. Marín, MD, PhD, Laboratorio de Optica, Departamento de Física, Universidad de Murcia, Campus Universitario de Espinardo, Edificio 34, 30071 Murcia, Spain. Email: josemaria.marin@um.es

doi:10.3928/1081597X-20230802-01

pecially at night. Extended depth of focus (EDOF) IOLs are an emerging technology to bridge the gap between the performance of monofocal and multifocal IOLs,[3] in terms of good visual acuity at different distances and the reduction of disturbing visual effects.[4] EDOF IOLs are designed to create an elongated focal zone to enhance the depth of focus (DOF), as opposed to monofocal IOLs (in which light is focused on one small range) or multifocal IOLs (which have two or three discrete focal points).[5] The benefit of using these lenses in terms of visual performance has been pointed out in several systematic reviews and meta-analyses.[5] There are different approaches to design EDOF IOLs, such as concentric optical zones, spherical aberration, small aperture, diffractive designs, and hybrid designs.[6] One of the traditional and effective alternatives is the induction of negative spherical aberration to extend DOF[7,8] by producing an elongated focal area.

On the other hand, IOLs are commonly biconvex. This considers the image quality on-axis and only optimizes the visual performance in the center of the visual field, overlooking their off-axis performance.[9] Peripheral vision is essential in the patient's spatial orientation,[10] in the control of posture,[11] and in detecting rapidly moving objects to prevent dangerous situations such as falls[12] or driving hazards.[13,14] The new IOLs used in this study (ArtIOL; Voptica SL) have an inverted meniscus design that improves off-axis optical quality and peripheral contrast sensitivity detection.[10] Based on the inverted meniscus design, the aspheric surfaces of the three different ArtIOL models (Art25, Art40, and Art70) have been designed to induce increasing amounts of negative spherical aberration to extend the DOF at different levels. The differences between the three models are the amount of spherical aberration induced by different aspherical profiles in the surfaces. In this context, we evaluated the visual performance, spectacle independence, and subjective quality of vision of the bilateral combination of Art40 and Art70 models. This combination was selected to ensure excellent far visual acuity and a moderate amount of DOF provided by the Art40 and good visual acuity at all distances using the wider DOF of the Art70.

PATIENTS AND METHODS

This prospective study involved 30 patients with bilateral implantation of ArtIOLs (Art40 and Art70) performed at the clinic Oftalvist, Murcia, Spain. The study was approved by the ethics committee of the University of Murcia. The research followed the tenets of the Declaration of Helsinki, and all participants gave a written informed consent before participating in the study.

Patients

Sixty eyes from 30 patients were included in the study. Inclusion criteria comprised patients with bilateral cataract, no current ocular pathology that could compromise visual acuity, no history of ocular surgery, corneal astigmatism less than 1.00 D, and not using ocular drugs that may affect vision.

IOL Description and Surgical Procedure

ArtIOLs lenses (CE-marked) are single-piece, foldable lenses of high refractive index hydrophobic acrylic material (ultraviolet light absorbing and blue light filtering) and C-loop haptics. The lenses have a 6-mm optical diameter and a total diameter of 13 mm. The ArtIOL models have an inverted meniscus aspheric design (**Figure A**, available in the online version of this article) to improve off-axis optical quality[10] reproducing the natural imaging proprieties of the crystalline lens, which minimizes the peripheral refractive errors in a large visual field.[9] The three different models have different increasing values of spherical aberration (Art25, Art40, and Art70). The lenses were offered to patients as EDOF IOLs available in Europe with the CE-mark.

All surgeries for the implantation of the binocular combination of Art40 and Art70 models were done by the same experienced surgeon (JMM), using femtosecond laser–assisted cataract surgery[15] for phacoemulsification extracapsular-type cataract extraction with a 2.2-mm temporal corneal incision and a capsulorhexis of 5 mm, under topical anesthesia. The IOL is intended for placement in the capsular bag. Ocular dominance was not taken into account because the Art70 did not significantly decrease the uncorrected distance visual acuity (UDVA). The two models, Art40 and Art70, were implanted indifferently in each eye. The surgery in the fellow eye was done 1 week after the first eye.

Examination Protocol and Measurements

In addition to other routine clinical tests, preoperative measurements included a complete biometric assessment using the IOLMaster (IOLMaster 700; Carl Zeiss Meditec). ArtIOLs designs, based on negative spherical aberration, permit stable visual acuity to be maintained over a range of viewing distances, increasing the DOF depending on the model. A-constant was determined to move this range to a myopic shift starting at far distance. This strategy improves intermediate and near vision while maintaining visual acuity at far. The SRK/T formula with an A-constant of 120 for both the Art40 and Art70 models was used for IOL power calculation. Emmetropia was the refractive target set in the IOLMaster to select the IOL power for both eyes and models.

Postoperative follow-up visits were scheduled by the clinic regular protocol, at 1 day after each eye surgery and between 4 and 6 weeks after the last surgery. During these visits, the visual and ocular status of the patient were examined and recorded in the patient's medical record. At 4 to 6 weeks postoperatively, manifest refraction, monocular and binocular UDVA and corrected distance visual acuity (CDVA) at 5 m were measured. Monocular and binocular distance-corrected defocus curves, from +1.00 to -3.00 D (0.50-D steps), were also obtained using trial lenses, considering the data from -1.50 and -2.50 D the distance-corrected intermediate visual acuity (DCIVA) at 60 cm and distance-corrected near visual acuity (DCNVA) at 40 cm, respectively. Additionally, monocular and binocular UDVA was measured with -1.50 and -2.50 D trial lenses to obtain data of uncorrected visual acuity at intermediate (UIVA) and near (UNVA) distances without any optical correction. During the study, a protocol amendment was implemented to include additional measurements of binocular uncorrected defocus curve from +1.00 to -3.00 D in the last 12 patients of the group of 30. Binocular distance-corrected defocus curve in 12 patients, implanted bilaterally with a standard biconvex monofocal IOL, was also measured as a reference control group. All visual acuity measurements were performed in photopic conditions with the same ambience illumination using a SLOAN chart projected with the ACP-8 (Topcon Corporation) projector at 85 cd/m^2. DOF, defined as the diopter range from 0.00 D onward, in which visual acuity is equal or superior to that 0.20 logMAR (20/32),[16] was calculated for the mean values of the different defocus curve measured.

Furthermore, monocular contrast sensitivity with and without distance correction was measured, in the same session (4 to 6 weeks postoperatively), using the preset contrast sensitivity test (M1) in the CC-100 XP LED LCD screen (Topcon Healthcare Solution) under the same photopic conditions as the visual acuity measurements. Along with the visual acuity and contrast sensitivity measurements, the 30 patients were surveyed for spectacle independence at far, intermediate, and near vision using the Patient Reported Spectacle Independence Questionnaire (PRSIQ).[17] The Quality of Vision (QoV) questionnaire[18] was also administered to evaluate photic phenomena: frequency, severity, and bothersomeness (with four levels of score) of 10 negative visual symptoms (glare, halos, starburst, etc). The handheld infrared Colvard (Oasis Medical)[19] pupillometer was used to evaluate the photopic pupil size for each patient.

Statistical Analysis

The statistical analysis was performed using Microsoft Excel 365 (Microsoft Corporation) and R Core Team and RStudio (R Foundation for Statistical Computing) software. The Shapiro-Wilk test was used to assess the normality of all variables analyzed. Nonparametric statistics were applied in non-normally distributed variables. Differences between variables were obtained by means of the Student's *t* test for normally distributed variables and the Wilcoxon signed-rank test for non-normally distributed variables. All statistical tests were two-tailed, and *P* values less than .05 were considered statistically significant. Inter-subject variability was evaluated by the standard deviation. To obtain statistically significant results according to a power analysis for comparing unpaired differences, a sample size of at least 23 eyes for each group was required to achieve a power of 0.80 and a two-tailed alpha level of 0.05, assuming the same values of expected differences between the means of visual acuity and standard deviations, because the accuracy in the visual acuity measurements corresponds to the steps of the letter lines in the visual acuity chart (ie, 0.1 in decimal visual acuity).

RESULTS

Refractive Outcomes and Postoperative Visual Acuity

Sixty eyes from 30 patients were included in the study, 16 women and 14 men, with a mean age of 70.3 ± 5.5 years (range: 58 to 81 years). In the 30 patients implanted binocularly with the Art40/Art70 combination, the mean IOL power was +21.88 ± 1.62 D (range: 18.00 to 24.50 D) for the Art40 and +22.03 ± 1.73 D (range: 18.00 to 24.50 D) for the Art70. There was no statistically significance difference between the IOL powers of both lens models ($P > .05$), ensuring that there were no patients with extreme IOL powers and the sample was homogenous in terms of axial length and keratometry.

Mean values, standard deviations, and ranges of postoperative refractive data, pupil diameter, and visual acuity are presented in **Table 1**. There was a statistically significant difference ($P < .05$) of the mean refractive spherical equivalent between the Art40 (-0.25 ± 0.32 D) and Art70 (-0.62 ± 0.38 D). Pupil diameter was the same for both IOL models, with mean values being 3.18 ± 0.48 mm. The mean values of UDVA were 0.01 (20/21) and 0.05 (20/23) logMAR for the Art40 and Art70, respectively, showing a small difference of 0.04 logMAR. Nevertheless, there were higher differences between the Art40 and Art70 for UIVA and UNVA. The mean UIVA (66 cm) was 0.11 and 0.02 logMAR for the Art40 and Art70, respectively, with a mean difference between lenses of one line. The mean UNVA (40 cm) was 0.33 logMAR (20/43) for the Art40 and 0.12 logMAR (20/26) for the Art70, almost two lines better for the Art70.

Defocus Curves

Mean monocular and binocular distance-corrected defocus curves from +1.00 to -3.00 D for the Art40, Art70, and Art40/70 are shown in **Figure 1**. The defocus curves were practically flat from +0.50 to -0.50 D for the Art40 and from +0.50 to -1.50 D for the Art70. Although the visual acuity was the same throughout the range, the best correction was the one that yielded the best subjective perception of letters. Thus, the use of myopic shift, -0.25 and -0.62 D in the Art40 and Art70, respectively, derived from the selection of the A-constant, optimized the flat range to enhance the visual acuity at intermediate and near distances. There was no statistical significance ($P > .05$) from +1.00 to -0.50 D between both IOL models, but eyes implanted with the Art70 had consistently better visual acuity from -1.00 D onward than those with the Art40 ($P < .05$). The binocular Art40/70 combination improved the visual acuity values at intermediate and near distances, from -1.00 to -3.00 D, with respect to monocular values, but the difference was not statistically significant for the Art70. Monocular DOF was 1.65 and 2.35 D for the Art40 and Art70, respectively, and the binocular Art40/70 combination increased the DOF up to 2.55 D.

Regarding uncorrected visual acuity measurements, the mean value of UDVA was zero logMAR (20/20) with the monocular Art40 and binocular Art40/Art70 combination, and it was slightly worse with the monocular Art70 at 0.05 ± 0.06 logMAR (20/22). At intermediate and near distances, binocular uncorrected visual acuity was 0.01 ± 0.03 and 0.09 ± 0.09 logMAR, respectively, without significant differences in comparison to the monocular Art70, whereas eyes with the monocular Art40 achieved values of visual acuity that were significantly lower.

Binocular UDVA and UIVA of 0 logMAR (20/20) was achieved by 28 (93.3%) and 24 (80%) of the patients, respectively, whereas a similar proportion, 24 (80%) patients, achieved a binocular UNVA of 0.1 logMAR (20/25) or better.

The mean values of binocular defocus curves of 12 patients implanted with the Art40/Art70 combination, both with and without distance correction, are presented in **Figure 2** along with the mean binocular values of a control group with monofocal IOLs in both eyes. At far distance and surroundings, between +1.00 and -0.50 D, the behavior of both binocular curves with the Art40/Art70 combination were similar ($P > .05$) to that of monofocal IOLs. As expected from -1.50 D onward, the benefit of the Art40/Art70 combination, without distance correction, was greater because viewing

TABLE 1

Postoperative Refractive Data, Pupil Diameter, and Visual Acuity (logMAR) Outcomes at 1 to 3 Months Postoperatively

Parameter	Art40 (n = 30)	Art70 (n = 30)
Sphere (D)		
Mean ± SD	-0.02 ± 0.29	-0.41 ± 0.34
Range	-0.50 to +0.75	-1.25 to +0.25
Cylinder (D)		
Mean ± SD	-0.49 ± 0.44	-0.44 ± 0.35
Range	-2.00 to 0.00	-1.50 to 0.00
Axis (°)		
Mean ± SD	78.93 ± 43.66	66.55 ± 48.42
Range	0.00 to 160	0.00 to 170.00
Spherical equivalent (D)		
Mean ± SD	-0.25 ± 0.32	-0.62 ± 0.38
Range	-0.75 to +0.62	-1.75 to +0.00
Pupil diameter (mm)		
Mean ± SD	3.18 ± 0.48	3.18 ± 0.48
Range	2.50 to 4.00	2.50 to 4.00
CDVA (logMAR)		
Mean ± SD	0.00 ± 0.00	0.00 ± 0.01
Range	0.00 to 0.00	0.00 to 0.05
UDVA (logMAR)		
Mean ± SD	0.01 ± 0.02	0.05 ± 0.06
Range	0.00 to 0.10	0.00 to 0.22
DCIVA (66 cm) (logMAR)		
Mean ± SD	0.16 ± 0.11	0.06 ± 0.06
Range	0.00 to 0.40	0.00 to 0.15
UIVA (66 cm) (logMAR)		
Mean ± SD	0.11 ± 0.11	0.02 ± 0.03
Range	0.00 to 0.40	0.00 to 0.10
DCNVA (40 cm) (logMAR)		
Mean ± SD	0.41 ± 0.15	0.24 ± 0.09
Range	0.10 to 0.70	0.05 to 0.40
UNVA (40 cm) (logMAR)		
Mean ± SD	0.33 ± 0.16	0.12 ± 0.10
Range	0.00 to 0.70	0.00 to 0.40

CDVA = corrected distance visual acuity; D = diopters; DCNVA = distance-corrected near visual acuity; DCIVA = distance-corrected intermediate visual acuity; SD = standard deviation; UDVA = uncorrected distance visual acuity; UIVA = uncorrected intermediate visual acuity; UNVA = uncorrected near visual acuity
The Art40 and Art 70 are manufactured by Voptica SL.

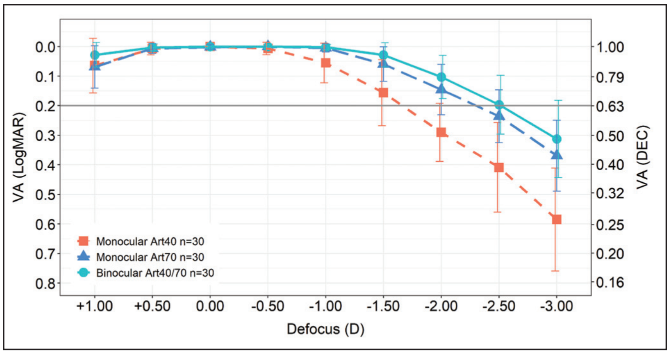

Figure 1. Mean values of monocular and binocular distance-corrected defocus curve for the Art40, Art70, and binocular Art40/70 combination (Voptica SL). D = diopters; DEC = decimal; VA = visual acuity

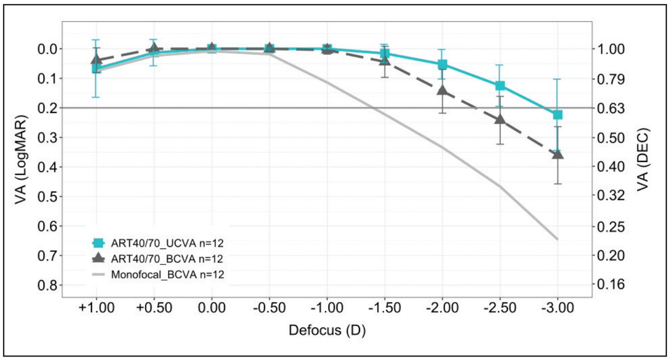

Figure 2. Binocular corrected distance and uncorrected defocus curves. The Art40/70 combination is manufactured by Voptica SL. D = diopters; DEC = decimal; VA = visual acuity

distances decreased. At near distances, from -2.00 to -3.00 D, uncorrected visual acuity of the Art40/Art70 combination was approximately 0.1 logMAR (20/25) better ($P < .05$) than CDVA. Patients with the Art40/Art70 combination significantly improved ($P < .05$) the mean DOF without optical correction, from 2.30 to 2.90 D, and it was much higher in comparison with the monofocal group (1.40 D).

To estimate the effect of the pupil size, the mean values of visual acuity of two groups of patients, one with pupil diameter between 2.5 and 3 mm (19 patients) and the other between 3.5 and 4 mm (10 patients), were calculated for both IOL models at three distances (far: -1.50 and -2.50 D) and with and without distance correction. In all conditions, the visual acuity was practically the same in both groups at far. At intermediate (-1.50 D) and near (-2.50 D), the values of visual acuity were better in the group with a smaller pupil size. The differences ranged between 0.01 and 0.08 logMAR, but in any condition that difference was statistically significant ($P > .05$).

Contrast Sensitivity

Figure B (available in the online version of this article) shows the monocular distance-corrected and uncorrected contrast sensitivity for both models of ArtIOLs. Distance-corrected contrast sensitivity mean values for the Art40 were 2.05 ± 0.12, 2.12 ± 0.30, 1.67 ± 0.32, and 1.33 ± 0.32 log units at 3, 6, 12, and 18 cycles per degree, respectively. In both cases, there were no statistically significant differences ($P > .05$) between the Art40 and Art70 at all tested frequencies (3, 6, 12, and 18 cycles per degree). No significant differences were found for each model with and without optical correction.

Questionnaires

Two of the 30 patients failed to complete the QoV and the PRSIQ. All patients answered “not at all” in the degrees of severity and bothersomeness for glare, hazy vison, blurred vision, distortion, and double vision, except in 2 patients, where one reported a few halos and the other a few starbursts. In the item of frequency, most of the patients never reported photic phenomena, only 1 patient saw occasional halos and blurred vision, and 2 patients saw starbursts.

Regarding the evaluation of spectacle independence from the PRSIQ, all 28 patients reported a high comfort level without glasses at far distance and most of them also at intermediate and close distances. The majority of patients (24 [85.7%]) never needed glasses for far and intermediate distances and 20 (71.4%) of them did not need glasses for near vision. None habitually used optical correction to far and intermediate viewing tasks. Only 6 of the 28 patients occasionally used near glasses to close viewing-specific tasks.

Discussion

The aim of the new platform of ArtIOLs was to make available to physicians a set of non-diffractive IOLs with different levels of DOF in an inverted meniscus design that also optimizes the peripheral optics. In this clinical study, the Art40 was selected as an IOL with a moderate increase of DOF and high visual quality at far in combination with the Art70 model, which provides an extended DOF. Our clinical results confirm that the bilateral combination for the Art40 and Art70 provides excellent visual acuity at far, intermediate, and near distances. Regarding the effect of the pupil size on visual acuity, although there were no significant differences between groups of patients with different pupil diameter, there was a tendency to improve the visual acuity at intermediate and near distances in the group of patients with a smaller pupil.

Although people spend most of their time under photopic conditions, the assessment of visual acuity only under photopic conditions is a limitation in this study, and further experiments should be performed to test visual performance under other illumination conditions.

The selection of the A-constant to calculate the IOL power with the SRK/T formula was previously programmed to place the beginning of the flat visual acuity range at far distance and extend the DOF toward intermediate and near distances. In this way, the final refractive results of mean manifest spherical equivalent were as expected, -0.25 and -0.62 D for the Art40 and Art70, respectively. This small residual defocus did not reduce the visual acuity in the Art40 and the minor decrease in visual acuity without correction was not statistically significant in the Art70.

We also compared the visual acuity at different distances of our IOLs with respect to those published with several current models of EDOF and diffractive multifocal IOLs[3-5,20-30] (**Table A**, available in the online version of this article). The Art40 IOL provides visual acuity results at all distances comparable with currently marketed EDOF IOLs. The Art40 and Vivity (Alcon Laboratories, Inc) IOLs have similar distance-corrected values of visual acuity at all distances. Uncorrected visual acuity of the Art40 is slightly better than that of the Vivity and Symfony (Johnson & Johnson Vision) at far and intermediate distances and similar at near. The Art70 provides a significantly better visual acuity than the Vivity and Symfony at all distances, and their values are comparable with diffractive trifocal IOLs: AT LISA tri 839MP (Carl Zeiss Meditec AG) and FineVision (PhysIOL). The binocular Art40/Art70 combination is compared to those results obtained with diffractive multifocal IOLs, AT LISA tri and PanOptix (Alcon Laboratories, Inc), with a sustained visual performance in the full range of vision.

A previous meta-analysis study[30] showed that the contrast sensitivity of the Symfony EDOF IOL could be better than trifocal models, especially under scotopic conditions. Despite the differences in spherical aberration of the Art40 and Art70, the values of contrast sensitivity are similar for all spatial frequencies and comparable with monofocal IOLs.[31]

Our findings disclose high patient satisfaction with the Art40/Art70 combination in terms of glasses independence and photic phenomena. The majority of the patients (71.4%) were completely independent of glasses. No patient habitually needed glasses, and only 21% of them used occasional near correction for close distances. Similar results of spectacle independence were only found with diffractive IOLs, such as the AT LISA tri and Symfony that allowed the most patients (85% and 79%, respectively) to wear glasses only for less than 1 hour a day.[29] Worse results were reported by different studies with the Vivity EDOF IOL: only 50%[4] and 30%[22] of the patients were independent of glasses. On the other hand, our patients reported in terms of visual disturbances that 100%, 96.4%, and 92.9% never experienced glare, halos, and starbursts. Arrigo et al[21] reported that 30% and 33% of patients implanted with the Vivity described halos and glare, respectively, whereas in the study of Gimenez-Calvo et al,[30] the AT Lisa tri and Symfony[31] never produced halos in 15% and 43% of the patients and glare in 69% and 50%, respectively.

The performance of bilateral implantation of the Art40 and Art70 provides a full range of focus and excellent visual results at all distances, while minimizing dysphotopsias. Compared to diffractive trifocal IOLs, the Art40/Art70 combination provides similar values of visual acuity at far, intermediate, and near distances, maintaining the visual performance in the full range of vision, with good values of contrast sensitivity and no limitations by optical phenomena.

AUTHOR CONTRIBUTIONS

Study concept and design (JMM, LH, EV, CR, PA); data collection (JMM, LH, CR, EA, IY); analysis and interpretation of data (JMM, LH, EV, CR, EA, IY, PA); writing the manuscript (JMM, LH, CR, EA); critical revision of the manuscript (JMM, LH, EV, IY, PA); statistical expertise (JMM, LH, EV); supervision (JMM, LH, EV, PA)

REFERENCES

1. Vilupuru S, Lin L, Pepose JS. Comparison of contrast sensitivity and through focus in small-aperture inlay, accommodating intraocular lens, or multifocal intraocular lens subjects. *Am J Ophthalmol*. 2015;160(1):150-62.e1. https://doi.org/10.1016/j.ajo.2015.04.023 PMID:25896457
2. Woodward MA, Randleman JB, Stulting RD. Dissatisfaction after multifocal intraocular lens implantation. *J Cataract Refract Surg*. 2009;35(6):992-997. https://doi.org/10.1016/j.jcrs.2009.01.031 PMID:19465282
3. Dick HB, Ang RE, Corbett D, et al. Comparison of 3-month visual outcomes of a new multifocal intraocular lens vs a trifocal intraocular lens. *J Cataract Refract Surg*. 2022;48(11):1270-1276. https://doi.org/10.1097/j.jcrs.0000000000000971 PMID:35545816
4. Kohnen T, Petermann K, Böhm M, et al. Nondiffractive wavefront-shaping extended depth-of-focus intraocular lens: visual performance and patient-reported outcomes. *J Cataract Refract Surg*. 2022;48(2):144-150. https://doi.org/10.1097/j.jcrs.0000000000000826 PMID:34653094
5. Liu J, Dong Y, Wang Y. Efficacy and safety of extended depth of focus intraocular lenses in cataract surgery: a systematic review and meta-analysis. *BMC Ophthalmol*. 2019;19(1):198. https://doi.org/10.1186/s12886-019-1204-0 PMID:31477053
6. Gatinel D, Loicq J. Clinically relevant optical properties of bifocal, trifocal, and extended depth of focus intraocular lenses. *J Refract Surg*. 2016;32(4):273-280. https://doi.org/10.3928/1081597X-20160121-07 PMID:27070236
7. Rocha KM, Soriano ES, Chamon W, Chalita MR, Nosé W. Spherical aberration and depth of focus in eyes implanted

with aspheric and spherical intraocular lenses: a prospective randomized study. *Ophthalmology*. 2007;114(11):2050-2054. https://doi.org/10.1016/j.ophtha.2007.01.024 PMID:17445897

8. Hervella L, Villegas EA, Robles C, Artal P. Spherical aberration customization to extend the depth of focus with a clinical adaptive optics visual simulator. *J Refract Surg*. 2020;36(4):223-229. https://doi.org/10.3928/1081597X-20200212-02 PMID:32267952

9. Jaeken B, Mirabet S, Marín JM, Artal P. Comparison of the optical image quality in the periphery of phakic and pseudophakic eyes. *Invest Ophthalmol Vis Sci*. 2013;54(5):3594-3599. https://doi.org/10.1167/iovs.13-11956 PMID:23640043

10. Villegas EA, Marín JM, Ginis H, et al. Peripheral refraction and contrast detection sensitivity in pseudophakic patients implanted with a new meniscus intraocular lens. *J Refract Surg*. 2022;38(4):229-234. https://doi.org/10.3928/1081597X-20220113-01 PMID:35412927

11. Berencsi A, Ishihara M, Imanaka K. The functional role of central and peripheral vision in the control of posture. *Hum Mov Sci*. 2005;24(5-6):689-709. https://doi.org/10.1016/j.humov.2005.10.014 PMID:16337294

12. Patino CM, McKean-Cowdin R, Azen SP. Central and peripheral visual impairment and the risk of falls and falls with injury. *Ophthalmology*. 2010;117(2):199-206.e1. https://doi.org/10.1016/j.ophtha.2009.06.063 PMID:20031225

13. Ortiz-Peregrina S, Casares-López M, Castro-Torres JJ, Anera RG, Artal P. Effect of peripheral refractive errors on driving performance. *Biomed Opt Express*. 2022;13(10):5533-5550. https://doi.org/10.1364/BOE.468032 PMID:36425634

14. Wolfe B, Dobres J, Rosenholtz R, Reimer B. More than the useful field: considering peripheral vision in driving. *Appl Ergon*. 2017;65:316-325. https://doi.org/10.1016/j.apergo.2017.07.009 PMID:28802451

15. Xu J, Li W, Xu Z, et al. Comparative visual outcomes of EDOF intraocular lens with FLACS vs conventional phacoemulsification. *J Cataract Refract Surg*. 2023;49(1):55-61. https://doi.org/10.1097/j.jcrs.0000000000001027 PMID:36104008

16. American National Standards Institute. ANSI Z80.35-2018: Ophthalmics—Extended Depth Of Focus Intraocular Lenses. American National Standards Institute. 2018.

17. Morlock R, Wirth RJ, Tally SR, Garufis C, Heichel CWD. Patient-Reported Spectacle Independence Questionnaire (PRSIQ): development and validation. *Am J Ophthalmol*. 2017;178:101-114. https://doi.org/10.1016/j.ajo.2017.03.018 PMID:28341605

18. McAlinden C, Pesudovs K, Moore JE. The development of an instrument to measure quality of vision: the Quality of Vision (QoV) questionnaire. *Invest Ophthalmol Vis Sci*. 2010;51(11):5537-5545. https://doi.org/10.1167/iovs.10-5341 PMID:20505205

19. Schnitzler EM, Baumeister M, Kohnen T. Scotopic measurement of normal pupils: Colvard versus Video Vision Analyzer infrared pupillometer. *J Cataract Refract Surg*. 2000;26(6):859-866. https://doi.org/10.1016/S0886-3350(00)00486-7 PMID:10889432

20. Rabinovich M, Ceresara G, Aramburu Del Boz A, al Khatib D, Crespe M, Bovet J. Visual outcomes after implantation of Lucidis EDOF IOL. *J Ophthalmol*. 2022;2022. https://doi.org/10.1155/2022/5100861

21. Arrigo A, Gambaro G, Fasce F, Aragona E, Figini I, Bandello F. Extended depth-of-focus (EDOF) AcrySof® IQ Vivity® intraocular lens implant: a real-life experience. *Graefes Arch Clin Exp Ophthalmol*. 2021;259(9):2717-2722. https://doi.org/10.1007/s00417-021-05245-6 PMID:34050809

22. Bala C, Poyales F, Guarro M, et al. Multicountry clinical outcomes of a new nondiffractive presbyopia-correcting IOL. *J Cataract Refract Surg*. 2022;48(2):136-143. https://doi.org/10.1097/j.jcrs.0000000000000712 PMID:34288635

23. Kohnen T, Suryakumar R. Extended depth-of-focus technology in intraocular lenses. *J Cataract Refract Surg*. 2020;46(2):298-304. https://doi.org/10.1097/j.jcrs.0000000000000109 PMID:32126045

24. Cochener B, Boutillier G, Lamard M, Auberger-Zagnoli C. A comparative evaluation of a new generation of diffractive trifocal and extended depth of focus intraocular lenses. *J Refract Surg*. 2018;34(8):507-514. https://doi.org/10.3928/1081597X-20180530-02 PMID:30089179

25. Rampat R, Gatinel D. Multifocal and extended depth-of-focus intraocular lenses in 2020. *Ophthalmology*. 2021;128(11):e164-e185. https://doi.org/10.1016/j.ophtha.2020.09.026 PMID:32980397

26. Ferreira TB, Marques EF, Rodrigues A, Montés-Micó R. Visual and optical outcomes of a diffractive multifocal toric intraocular lens. *J Cataract Refract Surg*. 2013;39(7):1029-1035. https://doi.org/10.1016/j.jcrs.2013.02.037 PMID:23680631

27. Mendicute J, Kapp A, Lévy P, et al. Evaluation of visual outcomes and patient satisfaction after implantation of a diffractive trifocal intraocular lens. *J Cataract Refract Surg*. 2016;42(2):203-210. https://doi.org/10.1016/j.jcrs.2015.11.037 PMID:27026443

28. Macías-Murelaga B, Garay-Aramburu G, Bergado-Mijangos R, et al. Prediction error stabilization and long-term standard results with a monofocal intraocular lens. *Vision (Basel)*. 2022;6(1):5. https://doi.org/10.3390/vision6010005 PMID:35076638

29. Webers VSC, Bauer NJC, Saelens IEY, et al. Comparison of the intermediate distance of a trifocal IOL with an extended depth-of-focus IOL: results of a prospective randomized trial. *J Cataract Refract Surg*. 2020;46(2):193-203. https://doi.org/10.1097/j.jcrs.0000000000000012 PMID:32126031

30. Giménez-Calvo G, Bartol-Puyal FA, Altemir I, et al. Influence of ocular biometric factors on the defocus curve in an enlarged depth-of-focus intraocular lens. *Int Ophthalmol*. 2023;43(3):945-955. https://doi.org/10.1007/s10792-022-02496-y PMID:36167943

31. Alio JL, Simonov A, Plaza-Puche AB, et al. Visual outcomes and accommodative response of the lumina accommodative intraocular lens. *Am J Ophthalmol*. 2016;164:37-48. https://doi.org/10.1016/j.ajo.2016.01.006 PMID:26829595

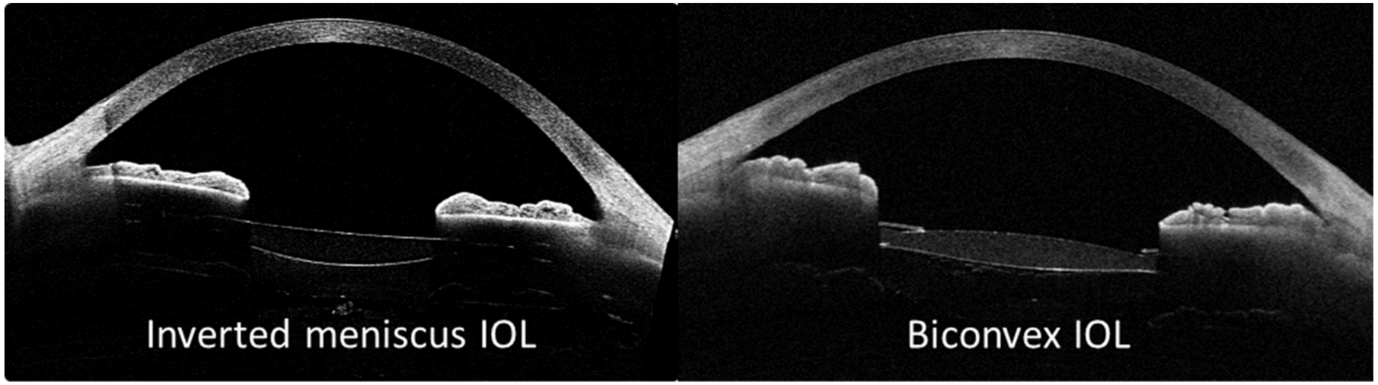

Figure A. Optical coherence tomography image of an ArtIOL (Voptica SL) implanted in comparison with a standard biconvex intraocular lens (IOL).

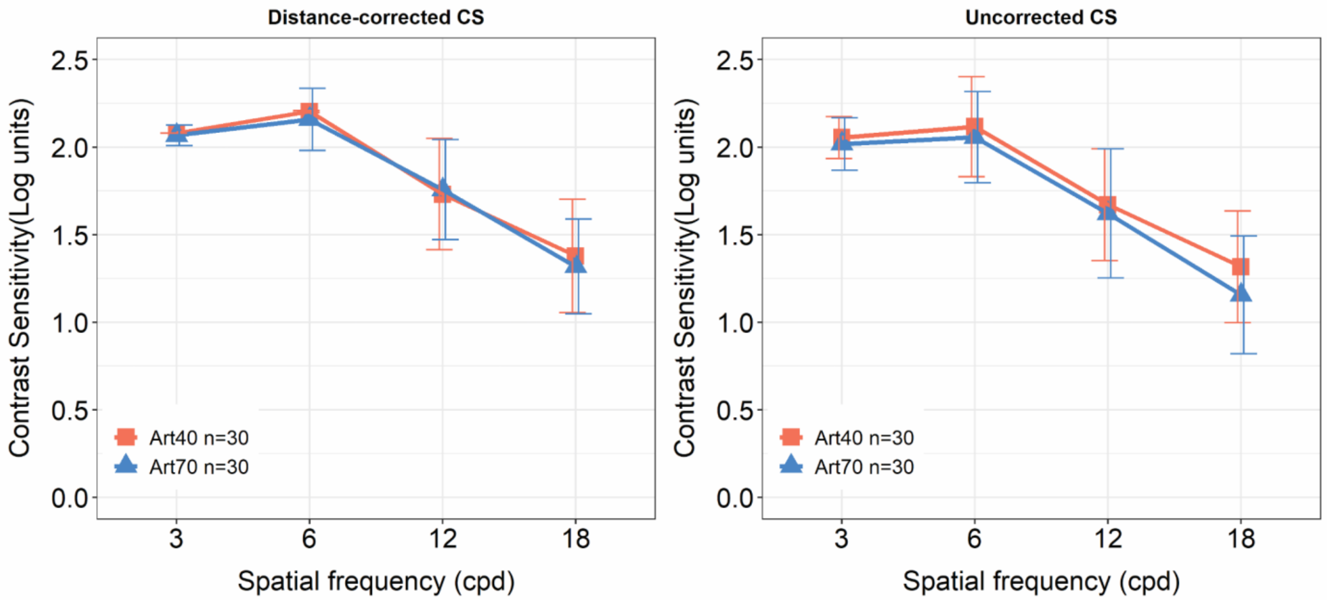

Figure B. Monocular distance-corrected and uncorrected contrast sensitivity (CS). The Art40 and Art70 are manufactured by Voptica SL. cpd = cycles per degree

TABLE A

Comparison Between Mean CDVA, UDVA, DCIVA, and UIVA Values of Monocular and Binocular Visual Acuity for ArtIOLs Models, EDOF IOLs (Vivity, Symfony), and Trifocal (AT Lisa tri, FineVision, PanOptix) IOLs

Visual Acuity	Monocular						Binocular		
	Art40 (n =30)	Art70 (n =30)	Vivity	Symfony	AT Lisa tri	FineVision	Art40/70	PanOptix	AT Lisa tri
CDVA (logMAR)	0.00 (0.00)	0.00 (0.01)	0.01 [22] 0.00 [23]				0	-0.02 [3]	
UDVA (logMAR)	0.01 (0.02)	0.05 (0.06)	0.12 [22]	0.08 [25]	0.04 [26]	0.01 [26]	0.00		0.03 [28]
DCIVA (66 cm) (logMAR)	0.16 (0.11)	0.06 (0.06)	0.15 [22] 0.16 [23]				0.03	0.02 [3]	
UIVA (66 cm) (logMAR)	0.11 (0.11)	0.02 (0.03)	0.14 [22]	0.21 [25]	0.00 [26]	0.08 [26]	0.01		0.10 [28]
DCNVA (40 cm) (logMAR)	0.41 (0.15)	0.24 (0.09)	0.32 [22] 0.41 [23]				0.20	0.07 [3]	
UNVA (40 cm) (logMAR)	0.33 (0.16)	0.12 (0.10)	0.32 [22]	0.29 [25]	0.07 [26]	0.00 [26]	0.09		0.15 [28]

CDVA = corrected distance visual acuity; DCIVA = distance-corrected intermediate visual acuity; DCNVA = distance-corrected near visual acuity; UDVA = uncorrected distance visual acuity; UIVA = uncorrected intermediate visual acuity; UNVA = uncorrected near visual acuity