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Comparison of the intermediate distance of a trifocal IOL with an extended depth-of-focus IOL: results of a prospective randomized trial



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Purpose: To compare visual outcomes, reading ability, and visual quality between the Symphony extended depth-of-focus intraocular lens (IOL) and the trifocal AT LISA tri 839MP IOL.

Setting: University Eye Clinic Maastricht, The Netherlands.

Design: Prospective randomized controlled trial.

Methods: Patients were randomly assigned to bilateral Symphony IOL or AT LISA tri 839MP IOL implantation. The primary outcome measure was uncorrected intermediate visual acuity (UIVA measured at 66 cm). Secondary outcomes included uncorrected distance visual acuity (UDVA), uncorrected near visual acuity (UNVA), reading ability, and comparison of defocus curves, contrast sensitivity, optical adverse effects, and quality of vision.

Results: The study enrolled 60 eyes of 30 patients. The mean UIVA was -0.02 ± 0.03 (SD) vs 0.01 ± 0.03 logarithm of the minimal angle of resolution (logMAR) in the Symphony and AT LISA tri 839MP groups,

respectively ($P = .047$). The UDVA was 0.01 ± 0.12 and -0.05 ± 0.07 logMAR ($P = .11$) and the UNVA was 0.09 ± 0.05 and 0.04 ± 0.07 logMAR ($P = .052$) in the Symphony and AT LISA tri 839MP groups, respectively. Reading ability was similar in both groups at 40 cm and 66 cm ($P = .87$ and $P = .14$, respectively). Less than 10% of patients in both groups experienced disabling glare. Patients experienced disabling halos in the AT LISA tri 839 MP group compared to the Symphony group in 39% and 21% of cases, respectively ($P = .12$). The mean score for visual functioning was 88.0 ± 14.1 in the trifocal group and 88.2 ± 10.9 for the EDOF group ($P = .96$).

Conclusions: The UIVA was better in the Symphony group than in the AT LISA tri 839MP group. No significant differences were seen in the binocular UNVA and UDVA, contrast sensitivity, reading ability, incidence of photopic phenomena, and patient satisfaction.

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Since the introduction of intraocular lenses (IOLs) in the treatment of cataract, the remedy for the post-operative loss of accommodation of the human eye has been an important topic of ongoing research. Bifocal IOLs provided an increased spectacle independence for reading when compared with a monofocal IOL.^{1,2} However, bifocal IOLs have limitations for performance at the intermediate distance.³ With the increased use of computers and tablets at the intermediate distance nowadays, trifocal IOLs were introduced that also provide good quality intermediate vision. Multiple trifocal IOL studies have shown a higher spectacle independence compared with bifocal and monofocal IOLs.³ However, some of the major side effects of bilateral trifocal or bifocal IOL implantation are the incidence

of photopic phenomena (eg, halos and glare) and the reduced visual acuity under mesopic circumstances compared with bilateral monofocal IOL implantation.^{1–5}

A few years ago, the TECNIS Symphony Extended Range of Vision ZXR00 IOL (Abbott Medical Optics, Inc.) was introduced to the armamentarium of presbyopia-correcting IOLs. According to the manufacturer, this IOL is theoretically providing a continuous range of high-quality vision for far, intermediate, and near distances with a low incidence of halos and glare comparable to monofocal IOLs under different light conditions.^{6–8}

The purpose of this prospective randomized study was to compare a commonly used trifocal IOL, the AT LISA tri 839MP (Carl Zeiss Meditec AG), and the TECNIS Symphony

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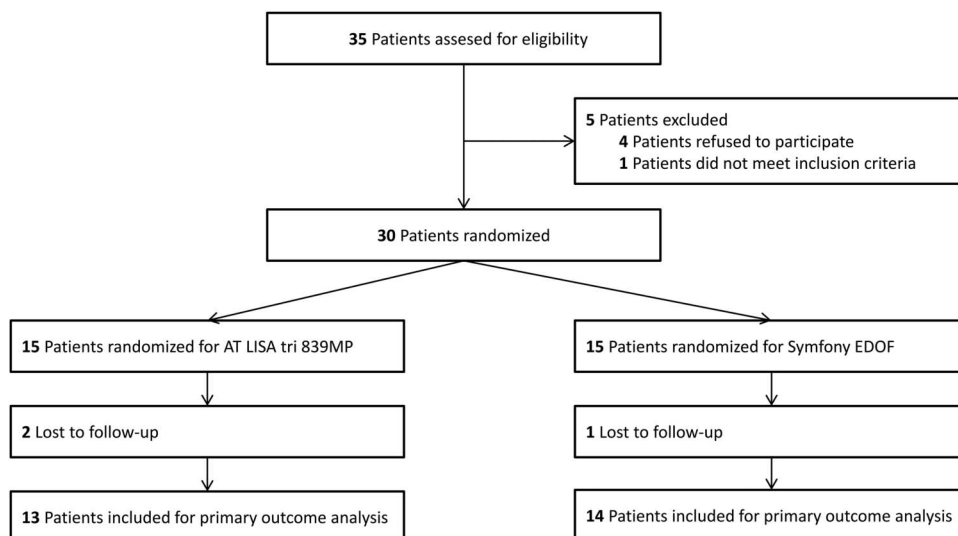


Figure 1. Randomization figure.

Extended Range of Vision ZXR00 IOL in terms of visual and refractive outcomes and analyze spectacle independence, optical side effects, and complications.

METHODS

Patients scheduled for cataract surgery and desiring spectacle independence were recruited from the Maastricht University Eye Clinic. Patients were randomized for bilateral implantation of the AT LISA tri 839MP IOL (AT LISA tri 839MP group) or blended implantation of the Symphony Extended Range of Vision ZXR00 IOL (Symphony group). The study protocol was approved by the ethics committee of the Maastricht University Medical Center. The study procedures were performed in accordance with the principles of the Declaration of Helsinki. The study protocol can be found at <https://clinicaltrials.gov> (identifier: NCT03117426).^A

The main inclusion criteria were bilateral cataract, expected postoperative astigmatism ≤ 1.00 diopters (D), and age 21 years or older. Exclusion criteria were irregular corneal astigmatism, previous intraocular or corneal surgery, Fuchs endothelial dystrophy, age-related macular degeneration, glaucoma, macular disease, and diabetic retinopathy.

Intraocular Lens Characteristics and Calculation

The AT LISA tri 839MP is a preloaded IOL with a single-piece diffractive trifocal design and made of hydrophilic acrylic with a hydrophobic surface. Based on theoretical calculation on the diffractive profile, the IOL has a light distribution of 50%, 20%, and 30% between far, intermediate, and near foci, respectively. It provides additions of +3.33 D and +1.66 D for near (40 cm) and intermediate (80 cm) vision, respectively. The IOL has a 6.0 mm optic with an overall length of 11.0 mm, a central trifocal zone over a diameter of 4.34 mm, and a peripheral bifocal zone from 4.34 to 6.0 mm. The dioptric power ranges from 0.0 to +32.0 D in 0.5 D increments.

The TECNIS Symphony ZXR00 is an aspheric biconvex hydrophobic acrylic IOL with a 6.0 mm optic and an 13.0 mm overall diameter. The IOL is designed with a proprietary method based on a combination of refractive and diffractive technologies for providing extended depth of focus and, therefore, extended range of vision with combined correction of spherical and chromatic aberration for contrast sensitivity enhancement.^B Nevertheless, two main foci can be assigned: a distance focus and an intermediate focus with an addition of +1.75 D.⁸ The IOL is available in powers from +5.0 to +34.0 D in 0.5 D increments.

For both IOLs, the Sanders–Retzlaff–Kraff formula was used for the calculation of the IOL power into the capsular bag using optical biometry (either IOLMaster series 500 or 700, Carl Zeiss Meditec). The optimized A-constants used were 119.1 for the Symphony IOL and 118.9 for the AT LISA tri 839MP IOL. In the AT LISA tri 839MP IOL group, emmetropia was targeted for postoperative mean refractive spherical equivalent (MRSE); in the Symphony group, the so-called micromonovision, with the dominant eye aimed to be emmetropic and the nondominant eye to be -0.5 D in MRSE.

Surgical Technique

All surgeries in this study were performed by 1 of 3 experienced surgeons (R.M.M.A.N., N.J.C.B., O.J.M.C.). In all eyes, a standard divide-and-conquer phacoemulsification technique or femtosecond laser-assisted cataract surgery was performed using a 2.2 mm clear corneal incision. In eyes with preexisting corneal astigmatism of 1.00 to 1.50 D, femtosecond laser-assisted arcuate incisions (LenSx, Alcon Laboratories, Inc.) were allowed to reduce the expected postoperative astigmatism within the desired range. Main incisions on the steep axis were performed in eyes with against-the-rule astigmatism between 0.75 D and 1.00 D to prevent increased postoperative residual astigmatism.

Table 1. Preoperative patient characteristics.

Parameter	AT LISA Tri 839 MP (n = 13)	Symphony ZXR00 EDOF (n = 14)
Age (y)		
Mean $\pm$ SD	70.38 $\pm$ 6.08	67.57 $\pm$ 12.21
Range	60, 79	37, 79
Mean binocular CDVA (logMAR) $\pm$ SD	0.21 $\pm$ 0.12	0.16 $\pm$ 0.17
Mean MRSE (D) $\pm$ SD	-0.91 $\pm$ 2.95	0.98 $\pm$ 2.73
Mean axial length (mm) $\pm$ SD	23.98 $\pm$ 1.73	23.13 $\pm$ 1.71
Mean corneal astigmatism (D) $\pm$ SD	-0.81 $\pm$ 0.46	-0.74 $\pm$ 0.42
Femtosecond laser arcuate incisions, n (%)	5 (19)	1 (4)
Temporal main incision, n (%)	1 (4)	2 (7)

CDVA = corrected distance visual acuity; EDOF = extended depth of focus; MRSE = manifest refraction spherical equivalent

Table 2. Postoperative refractive outcomes and uncorrected visual acuity at near, intermediate, and far.

Parameter	AT LISA Tri 839 MP (n = 13)	Symfony ZXR00 EDOF (n = 14)		P Value
	Both Eyes Combined	Dominant Eye	Nondominant Eye	
Spherical error (D)				
Mean $\pm$ SD	0.40 $\pm$ 0.23	0.07 $\pm$ 0.50	-0.25 $\pm$ 0.56	—
Range	0.00, 0.75	-1.25, 0.75	-1.50, 0.50	
Residual astigmatism (D)				
Mean $\pm$ SD	-0.50 $\pm$ 0.43	-0.63 $\pm$ 0.41	-0.70 $\pm$ 0.58	—
Range	-1.50, 0.00	-1.50, 0.00	-2.00, 0.00	
MRSE (D)				
Mean $\pm$ SD	0.13 $\pm$ 0.32	-0.24 $\pm$ 0.51	-0.60 $\pm$ 0.60	—
Range	-0.50, 0.75	-1.75, 0.38	-2.13, 0.25	
Mean photopic $\pm$ SD				
Binocular UDVA @ 4 m (logMAR)	-0.05 $\pm$ 0.07	0.01 $\pm$ 0.12		.11
Binocular UIVA @ 66 cm (logMAR)	0.01 $\pm$ 0.03	-0.02 $\pm$ 0.03		.047
Binocular UNVA @ 40 cm (logMAR)	0.04 $\pm$ 0.07	0.09 $\pm$ 0.05		.052
Mean mesopic $\pm$ SD				
Binocular UDVA @ 4 m (logMAR)	0.08 $\pm$ 0.10	0.11 $\pm$ 0.11		.48
Binocular UIVA @ 66 cm (logMAR)	0.14 $\pm$ 0.09	0.10 $\pm$ 0.05		.12
Binocular UNVA @ 40 cm (logMAR)	0.21 $\pm$ 0.10	0.20 $\pm$ 0.15		.87

EDOF = extended depth of focus; logMAR = logarithm of the minimum angle of resolution; MRSE = manifest refraction spherical equivalent; UDVA = uncorrected distance visual acuity; UIVA = uncorrected intermediate visual acuity; UNVA = uncorrected near visual acuity

Randomization

Consecutive patients were randomly assigned to the Symfony or the AT LISA tri 839MP group. Block randomization was performed with a block size of 4 patients to reduce bias and achieve balance in allocation of participants in both treatment arms. The patient and the investigator performing the postoperative examinations were masked to the treatment allocation. At the 3-month follow-up, the randomization was disclosed.

Preoperative Assessment

Preoperatively, each patient had a full ophthalmologic evaluation using slitlamp biomicroscopy, funduscopy, and intraocular pressure measurement. Automated keratometry (partial coherence interferometry based), optical biometry (IOLMaster series 500 or 700), pupillometry (P2000 SA pupillometer, Procyon Instruments Ltd.), and corneal topography (Pentacam, Oculus Optikgeräte GmbH) were performed before surgery.

Postoperative Assessment

At all postoperative visits (1 week, 1 month, and 3 months), the monocular uncorrected distance visual acuity (UDVA) and corrected distance visual acuity (CDVA) were measured using Early Treatment Diabetic Retinopathy Study charts at 4 m.

Patients were asked to start reading the charts at the smallest row on which all letters were easily distinguishable, proceeding until no letters on a row were read correctly. The correct number of letters was noted and transferred into logarithm of the minimal angle of resolution (logMAR) values for further analysis. In addition, at the 1-month and 3-month postoperative visits, the binocular UDVA and CDVA and binocular uncorrected near visual acuity (UNVA, 40 cm) and intermediate visual acuity (UIVA, 66 cm) were measured. At the final follow-up visit, all visual acuity measurements were obtained under photopic (≥ 80 cd/m² luminance) and mesopic (≤ 10 cd/m² luminance) conditions. Furthermore, binocular defocus curves were obtained at the final visit in photopic and mesopic conditions. During the defocus test, increments of 0.50 D were added (range -4.0 to +2.0 D) to the CDVA in both eyes to produce defocus.

Reading Ability

The Salzburg Reading Desk (Version 1.0, SRD Vision LLC) was used to measure the reading ability at near and intermediate distances. This device has been described in several studies and allows for measuring reading acuity in logMAR and reading speed in words per minute at a predetermined or subjectively preferred

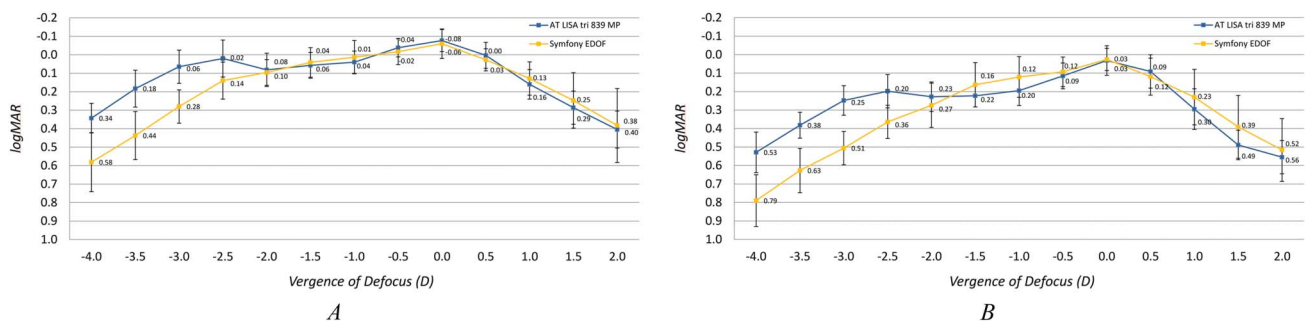


Figure 2. Defocus curves. *A*, Defocus curve for both IOLs in photopic conditions. *B*, Defocus curve for both IOLs in mesopic conditions (IOL = intraocular lens).

Table 3. Reading ability at near and intermediate distance under photopic and mesopic conditions.

Parameter	At Testing Distance*		At Preferred Distance		Preferred Distance (cm)
	LogMAR	WPM	LogMAR	WPM	
Photopic conditions					
Near distance*					
AT LISA tri 839 MP	0.08	114	0.07	116	36
Symfony ZXR00	0.08	116	0.07	107	41
EDOF					
P value	.87	.77	.99	.29	—
Intermediate distance†					
AT LISA tri 839 MP	0.10	111	0.05	96	75
Symfony ZXR00	0.07	125	0.04	117	64
EDOF					
P value	.14	.34	.71	.09	—
Mesopic conditions					
Near distance*					
AT LISA tri 839 MP	0.33	107	0.31	113	35
Symfony ZXR00	0.32	105	0.31	105	40
EDOF					
P value	.77	.086	.92	.58	—
Intermediate distance†					
AT LISA tri 839 MP	0.30	108	0.27	99	70
Symfony ZXR00	0.28	111	0.24	95	63
EDOF					
P value	.82	.80	.34	.70	—

EDOF = extended depth of focus; logMAR = logarithm of the minimum angle of resolution; WPM = words per minute (reading threshold 80 WPM)

*Testing distance 40 cm for near and 66 cm for intermediate.

reading distance.^{9–14} The device consists of a high-resolution monitor on which log-scaled Colenbrander sentences are displayed, and a laptop computer on which the operating software is displayed. The reading distance is measured by 2 infrared video cameras. A microphone is used to determine the reading time and reading speed. The Colenbrander sentences are presented in progressively smaller print sizes, and different photopic and mesopic conditions can be simulated. A reading speed of a minimum of 80 words per minute is accepted.

A fixed distance of 66 cm and 40 cm was used for measuring intermediate and near vision, respectively. Both distances were tested under photopic (100% contrast and 100 cd/m² luminance) and mesopic (30% contrast and 20 cd/m² luminance) conditions. In addition, patients were asked to freely choose a patient-preferred reading distance for both intermediate and near vision.

Contrast Sensitivity

The CSV-1000 system (Vector Vision Inc.) was used to measure contrast sensitivity under photopic and mesopic conditions.

Special spectacles with mesopic lenses (Vector Vision Inc.) were used to simulate mesopic circumstances. Binocular contrast sensitivity at 4 m was obtained at the 3-month follow-up with correcting spectacles if necessary.

Spectacle Independence, Photopic Phenomena, and Quality of Vision

Postoperative validated questionnaires at 3 months were obtained to evaluate the percentage of patients with spectacle independence, the incidence of photopic phenomena (eg, halos and glare), and vision-related quality of life (VQOL). Spectacle dependence was expressed by a frequency score varying from 1 (always) to 5 (never). The validated Visual Functioning Questionnaire (VF-14) determined the amount of trouble patients had with vision-related daily activities (eg, reading and driving) and ranged from 0 to 100 (higher scores meaning better functioning).^{15,16} The VQOL was expressed by a VCM1 (Core Module) score, ranging from 0 (best possible VQOL) to 5 (worst possible VQOL).¹⁷

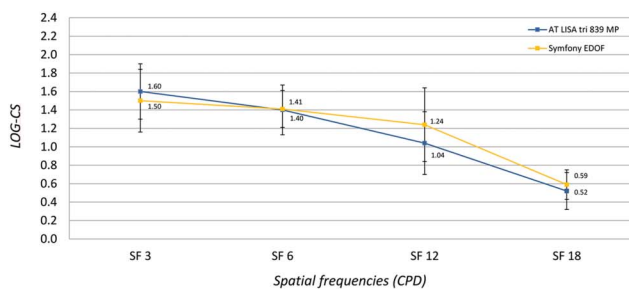
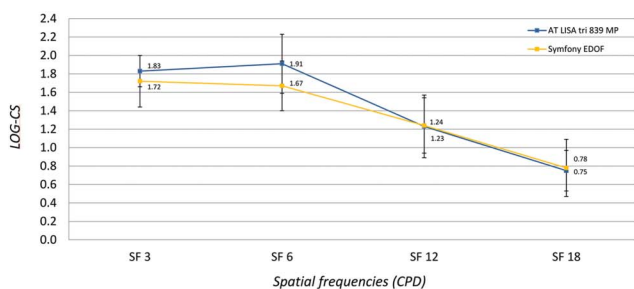


Figure 3. Contrast sensitivity charts. *A*, Contrast sensitivity for both IOLs in photopic conditions. *B*, Contrast sensitivity for both IOLs in mesopic conditions. CS = contrast sensitivity (cpd = cycles per degree; IOL = intraocular lens).

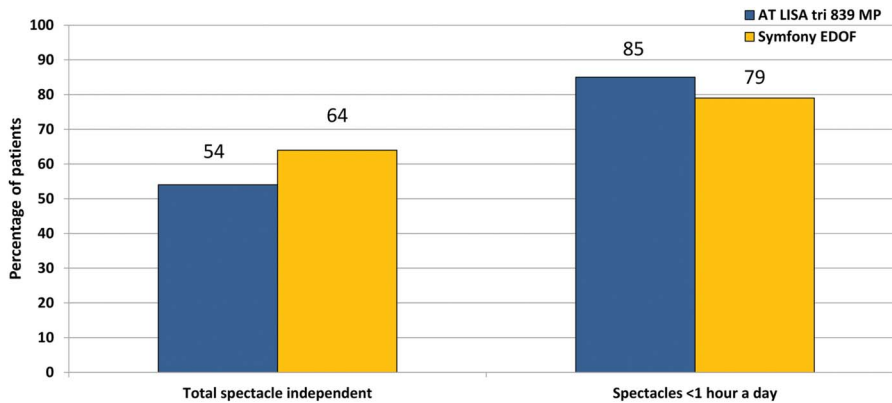


Figure 4. Spectacle independence. Percentage of patients in both groups with total spectacle independence after bilateral surgery and the percentage of patients who only required spectacles for less than 1 hour a day (EDOF = extended depth of focus).

Sample Size

The calculation of the sample size was based on the primary outcome of binocular uncorrected visual acuity at the intermediate distance (66 cm). In a prospective study with a binocular AT LISA tri 839MP IOL, a binocular uncorrected visual acuity at the intermediate distance (66 cm) of 0.08 ± 0.10 logMAR was found.¹⁸ To find a clinically significant difference between the 2 groups, a difference of 0.14 logMAR (difference of 7 letters on the Early Treatment Diabetic Retinopathy Study chart) was assumed. Based on these assumptions ($\alpha = 0.05$ and power = 0.9), 12 patients were required in each group. Assuming a drop out of less than 20% on the primary outcome measure, 30 patients needed to be included.

Statistical Analysis

All data were collected in an electronic data capture system for medical research (Castor EDC, CIWIT B.V.) and transferred to SPSS for Windows software (version 23.0, 2010, IBM Corp.) for data analysis. To evaluate differences between the 2 groups, independent Student *t* tests was used. Furthermore, paired *t* tests were used to analyze changes in visual acuities between the preoperative and postoperative visits. If the distribution of variables was not normal, the nonparametric Mann-Whitney *U* test was used. In all tests, the threshold of statistical significance was assumed equal to a *P* value of 0.05.

RESULTS

A total of 30 patients (60 eyes) were randomly assigned to the Symphony or the AT LISA tri 839MP group (Figure 1). The Symphony group comprised 15 patients (11 women [73%]) with a mean age of 70 years (range 60 to 79 years). The AT LISA tri 839MP group comprised 15 patients (9 women [15%]) with a mean age of 68 years (range 37 to 79 years). Preoperatively, there were no statistically significant differences in age, binocular CDVA, MRSE, axial length, or corneal astigmatism between both groups (Table 1).

A total of 3 patients were lost to follow-up because of personal reasons, 2 in the AT LISA tri 839MP group and 1 in the Symphony group. Additional intraoperative femtosecond laser-assisted arcuate incisions were performed in 5 eyes (19%) in the AT LISA tri 839MP group and in 1 eye (4%) in the Symphony group. Temporal incisions were performed in 4% (*n* = 1) of eyes in the AT LISA tri 839MP group and in 7% (*n* = 2) of eyes in the Symphony group (Table 1).

Visual Acuity and Refraction

Table 2 shows the achieved refractive outcomes and binocular uncorrected visual acuity at distance, intermediate, and near under photopic and mesopic conditions at the final postoperative visit at 3 months. No significant differences were found in the UDVA and UNVA. A small significant difference was found in UIVA between both groups ($P = .047$, Mann-Whitney *U* test) in favor of the Symphony group. A decrease in visual acuity at all distances was seen in both groups when measuring under mesopic vs photopic conditions ($P \leq .05$, Mann-Whitney *U* test). No differences in visual acuity at all distances were seen between groups under mesopic conditions ($P \geq .05$, Mann-Whitney *U* test).

At 3 months postoperatively, the mean MRSE was $-0.24 \text{ D} \pm 0.51$ (SD) and -0.60 ± 0.60 D in the Symphony group for the dominant and nondominant eyes, respectively. The mean MRSE in the AT LISA tri 839MP group was 0.13 ± 0.32 D. No significant differences were found in the mean residual astigmatism between both groups ($P \geq .05$, Mann-Whitney *U* test). A total of 8% and 11% of patients had a residual astigmatism of 1.5 D or more in the AT LISA tri 839MP and Symphony groups, respectively.

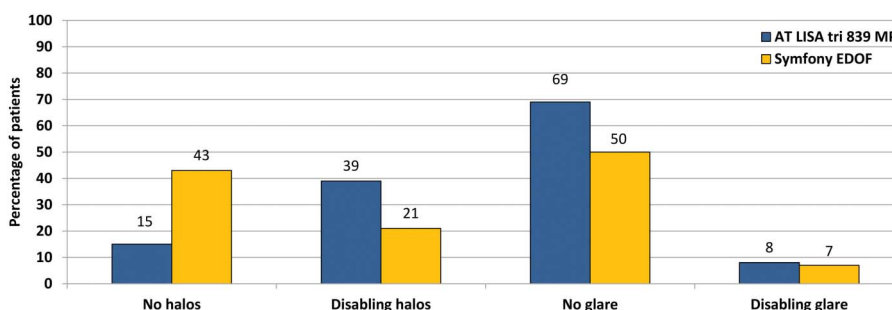


Figure 5. Percentage of patients in both groups experiencing no photopic phenomena (halos or glare) and the percentage of patients experiencing disabling halos and glare (EDOF = extended depth of focus).

Table 4. Overview of prospective studies reporting clinical outcomes in logMAR after Symphony EDOF IOL implantation.

Author	Study Design	Eyes (n)	MRSE (D)	UDVA		UIVA	
				Distance (m)	LogMAR	Distance (cm)	LogMAR
Pedrotti et al. ¹⁹	Prospective case series	50	-0.27 ± 0.47	4	0.00 ± 0.09	60	0.10 ± 0.09
Cochener ²⁰	Prospective case series	224	-0.21 ± 0.38 (dominant) -0.75 ± 0.52 (nondominant)	4	0.04 ± 0.11	70	0.09 ± 0.17
Cochener ²⁰	Prospective case series	585	-0.30 ± 1.13	4	0.03 ± 0.09	70	0.13 ± 0.16
Ruiz-Mesa et al. ²¹	Prospective case series	40	-0.19 ± 0.18	4	0.01 ± 0.02	60	0.09 ± 0.08
Monaco et al. ²²	RCT	40	-0.23 ± 0.03	4	0.00 ± 0.04	67	0.23 ± 0.07
Pedrotti et al. ²³	Prospective case series	60	-0.08 ± 0.28	4	-0.04 ± 0.09	60	0.05 ± 0.09
Menucci et al. ²⁴	Prospective case series	40	-0.13 ± 0.61 D	4	-0.04 ± 0.05	80	0.07 ± 0.07
Ganesh et al. ²⁵	Prospective case series	50	-0.22 ± 0.37 D (dominant) -0.74 ± 0.44 D (nondominant)	4	-0.04 ± 0.09	60	0.05 ± 0.09
Ganesh et al. ²⁵	Prospective case series	50	-0.22 ± 0.37 D (dominant) -0.74 ± 0.44 D (nondominant)	4	-0.04 ± 0.09	80	-0.04 ± 0.09
Kohnen et al. ²⁶	Prospective case series	52	-0.17 ± 0.30 D	4	-0.02 ± 0.07	80	0.01 ± 0.07
Kohnen et al. ²⁶	Prospective case series	52	-0.17 ± 0.30 D	4	-0.02 ± 0.07	60	0.08 ± 0.18

EDOF = extended depth of focus; IOL = intraocular lens; logMAR = logarithm of the minimal angle of resolution; MRSE = mean refraction spherical equivalent; NA = not available (not reported); RCT = randomized controlled trial; UDVA = uncorrected distance visual acuity; UIVA = uncorrected intermediate visual acuity; UNVA = uncorrected near visual acuity

Figure 2 shows the defocus curves for both groups under photopic and mesopic conditions. The photopic defocus curve showed best visual acuity (0.02 and -0.08 logMAR) at -2.5 D and 0.0 D for the AT LISA tri 839MP group. Between these 2 peaks, the visual acuity dropped to 0.08 logMAR at -2.0 D. In the Symphony group, there was a more continuously increasing visual acuity seen between -2.5 D and 0.0 D, with a best visual acuity of -0.06 logMAR at 0.0 D. Under mesopic conditions, the defocus curve showed a best visual acuity in the AT LISA tri 839MP group of 0.20 logMAR at -2.5 D and 0.03 logMAR at 0.0 D, with a lowest visual acuity of 0.23 logMAR at -2.0 D. The Symphony group showed a continuously increasing visual acuity between -1.5 D and 0.0 D, with a best visual acuity at 0.0 D of 0.03 logMAR. The AT LISA tri 839MP group scored significantly better from -4.0 to -2.5 D ($P < .05$, Mann-Whitney U test) compared with the Symphony group.

Reading Ability

Table 3 demonstrates the reading ability for both groups at different distances measured with the SRD under photopic and mesopic conditions. No significant differences were seen between both groups in reading ability at 40 cm, 66 cm, or the preferred distance for near and intermediate distances under photopic conditions ($P \geq .05$, Mann-Whitney U test). The preferred near reading distance was 36 cm in the AT LISA tri 839MP group, whereas this distance was 41 cm in the Symphony group. A larger difference was seen at the intermediate distance, with preferred reading distances of

75 cm in the AT LISA tri 839MP group and 64 cm in the Symphony group.

Under mesopic conditions, no differences were found in reading ability at 40 cm, 66 cm, or the preferred distance for near and intermediate distances ($P \geq .05$, Mann-Whitney U test). The preferred reading distances in the AT LISA tri 839MP group were 35 cm and 70 cm, whereas the preferred reading distances in the Symphony group were 40 cm and 63 cm for near and intermediate distances, respectively.

Contrast Sensitivity

Figure 3 shows the contrast sensitivity for both groups under photopic and mesopic conditions. The mean contrast sensitivity under photopic conditions was 1.43 ± 0.54 and 1.35 ± 0.47 for the AT LISA tri 839MP and Symphony groups, respectively ($P \geq .05$). No significant difference in contrast sensitivity was noted between the AT LISA tri 839MP and Symphony group under mesopic conditions with mean values of 1.14 ± 0.50 vs 1.19 ± 0.46 , respectively ($P \geq .05$).

Spectacle Independence, Photopic Phenomena, and Quality of Vision

Figure 4 shows the percentage of patients achieving total spectacle independency and the percentage of patients using spectacles less than 1 hour a day for specific daily tasks. No statistical significant differences were seen between both groups. More than 50% of patients were totally spectacle independent 3 months postoperatively. A slightly higher percentage of patients in the Symphony group

Table 4. Continued.

UNVA		Halos (%)		Glare (%)		Total Spectacle Independence (%)
Distance (cm)	LogMAR	Any	Disabling	Any	Disabling	
40	0.18 ± 0.08	NA	NA	NA	NA	NA
40	0.17 ± 0.18	NA	4	NA	1	≤81
40	0.21 ± 0.16	NA	3	NA	2	≤72
40	0.17 ± 0.06	NA	NA	NA	NA	0.9
40	0.02 ± 0.06	95	20	90	12	0.7
40	0.18 ± 0.10	NA	NA	NA	NA	NA
40	0.25 ± 0.08	70	NA	50	NA	60
40	0.15 ± 0.11	NA	NA	NA	NA	84
40	0.15 ± 0.11	NA	NA	NA	NA	84
40	0.22 ± 0.15	54	NA	33	NA	71
40	0.22 ± 0.15	54	NA	33	NA	71

achieved total spectacle independency compared with the AT LISA tri 839MP group. Eighty-five percent and 79% of patients needed no spectacles at all or only 1 hour a day in the AT LISA tri 839MP and Symphony groups, respectively.

Figure 5 demonstrates that 43% of patients in the Symphony group experienced no halos vs 15% in the AT LISA tri 839MP group ($P=.12$). Disabling halos (score 4 to 5 on the Likert scale) were reported in almost twice as many patients (39% vs 21%) in the AT LISA tri 839MP group compared with the Symphony group; however, no statistically significant difference was found ($P=.33$). More than 50% of patients in both groups did not report glare, and less than 10% of patients in both groups experienced disabling glare. Disabling glare (8% vs 7%; $P=.96$) was mentioned less often compared with disabling halos (39% vs 21%) in the AT LISA tri 839MP and Symphony groups, respectively.

The mean score for visual functioning regarding vision-related daily activities was 88.0 ± 14.1 for the AT LISA tri 839MP group and 88.2 ± 10.9 for the Symphony group ($P=.96$). The VQOL was excellent in both groups, with a mean score of 0.33 ± 0.42 for the AT LISA tri 839MP group and 0.29 ± 0.55 for the Symphony group ($P=.81$).

Ninety-two percent and 93% of patients for the AT LISA tri 839 and Symphony groups (13 out of 14 patients) would recommend the implanted IOL to family or friends, respectively.

Complications and Adverse Events

No surgical complications were reported. Postoperatively, neodymium:YAG laser capsulotomy to treat posterior capsule opacification was performed in 1 patient (1 eye) in both groups. After fulfilling all control visits, a total of 3 patients (1 in the AT LISA tri 839MP group and 2 in the Symphony group) underwent laser-assisted subepithelial keratectomy to correct a myopic residual refractive error or residual astigmatism.

DISCUSSION

The purpose of this study was to compare the clinical outcomes of a commonly used presbyopia-correcting

trifocal IOL (AT LISA tri 839MP) vs a novel IOL design with an extended range of vision to correct presbyopia (TECNIS Symphony), with the primary outcome being intermediate vision. At 3 months postoperatively, a significant difference in UIVA was found in favor of the Symphony group. However, it is questionable if this small difference of 0.03 logMAR is clinically relevant. No significant differences were seen in the binocular uncorrected visual acuity at near or distance contrast sensitivity, reading ability under both photopic and mesopic conditions, incidence of photopic phenomena, and patient satisfaction. However, the study was not powered to look at these secondary outcomes. The defocus curves of the Symphony group under photopic conditions showed a more continuous increase in visual acuity between -2.5 D and 0.0 D compared with the AT LISA tri 839MP group, where 2 distinct peaks at -2.5 D and 0.0 D were identified.

With the increasing use of computers and tablets at the intermediate distance, the correction and spectacle independence for this distance becomes increasingly important for a broad patient population. The introduction of trifocal IOLs was the first step toward improved uncorrected intermediate vision. However, since the introduction of the extended range of vision IOLs, a new alternative for excellent intermediate vision is available. Because of the design, a continuous optimum vision from far to near could be obtained in combination with a decreased occurrence of photopic phenomena.⁶⁻⁸ To our knowledge, no studies are available comparing this extended range of vision IOL design with the commonly used AT LISA tri 839MP IOL for the intermediate distance in a prospective randomized controlled trial.

Table 4 provides an overview of the currently available prospective case series and randomized controlled trials evaluating the TECNIS Symphony IOL.¹⁹⁻²⁶ In our study, the primary outcome measure was binocular UIVA at 66 cm. The current literature concerning the Symphony IOL is limited. Most studies report UIVA for distances measured between 60 cm and 70 cm. Because none of these studies determined the UIVA at 66 cm, the UIVA determined in

Table 5. Overview of prospective studies reporting clinical outcomes in logMAR after AT LISA tri 839MP IOL implantation.

Author	Study Design	Eyes (n)	MRSE (D)	UDVA		UIVA	
				Distance (m)	LogMAR	Distance (cm)	LogMAR
Mojzis et al. ¹⁸	Prospective case series	60	-0.12 ± 0.39	4	-0.03 ± 0.09	66	0.08 ± 0.10
Mojzis et al. ²⁷	Prospective case series	120	-0.08 ± 0.39	4	0.03 ± 0.13	80	0.11 ± 0.13
Mojzis et al. ²⁷	Prospective case series	120	-0.08 ± 0.39	4	0.03 ± 0.13	66	0.12 ± 0.13
Kretz et al. ²⁸	Prospective case series	100	-0.08	4	0.04	66	0.04
Marques et al. ²⁹	Prospective case series	30	-0.02 ± 0.39	4	0.00 ± 0.01	80	0.13 ± 0.42
Mendicutte et al. ³⁰	Prospective case series	208	0.35 ± 0.28	4	0.03 ± 0.09	80	0.10 ± 0.15
Kohnen et al. ³¹	Prospective case series	54	NA	4	-0.06 ± 0.10	80	0.00 ± 0.12
Bilbao-Calabuig et al. ³²	Restrospective study	8564	0.26 ± 0.47	4	-0.01 ± 0.06	80	-0.05 ± 0.14
Kaymak et al. ³³	RCT	26	0.29 ± 0.37	4	-0.02 ± 0.08	70	0.12 ± 0.12
Kaymak et al. ³³	RCT	26	0.29 ± 0.37	4	-0.02 ± 0.08	80	0.10 ± 0.11
Mencucci et al. ³⁴	Prospective case series	42	NA	4	0.00 ± 0.05	80	0.11 ± 0.07
Alió et al. ³⁵	RCT	32	NA	4	-0.03 ± 0.07	80	0.11 ± 0.14
Alió et al. ³⁵	RCT	32	NA	4	-0.03 ± 0.07	70	0.14 ± 0.16
Menucci et al. ²⁴	Prospective case series	40	-0.16 ± 0.55 D	4	0.00 ± 0.02	80	0.11 ± 0.07
Xiamin et al. ³⁶	Prospective case series	50	NA	4	0.02 ± 0.09	80	0.08 ± 0.10
Yang et al. ³⁷	Prospective case series	52	NA	4	0.05 ± 0.10	66	0.23 ± 0.12

IOL = intraocular lens; logMAR = logarithm of the minimal angle of resolution; MRSE = mean refractive spherical equivalent; NA = not available (not reported); RCT = randomized controlled trial; UDVA = uncorrected distance visual acuity; UIVA = uncorrected intermediate visual acuity; UNVA = uncorrected near visual acuity

our study at 66 cm cannot be compared with the current literature. In terms of measurement distance of UDVA (4 m) and UNVA (40 cm), several prospective studies are available to compare with our results.^{19–26} The current literature shows an excellent UDVA for the Symphony IOL in nearly all studies (range 0.04 to -0.04 logMAR). For UNVA, most studies show a much lower logMAR visual acuity at 40 cm (range 0.25 to 0.02 logMAR). The present study also showed an excellent UDVA and a slightly better UIVA and UNVA compared with previous studies.^{19–26} In our study, we aimed for micromonovision with the dominant eye to be emmetropic and the nondominant eye to have a slightly myopic MRSE (target -0.50 D). Both the dominant and nondominant eyes in our study population achieved a slightly more myopic outcome in terms of MRSE as desired (-0.24 D and -0.60 D, respectively). We believe that this minor myopic outcome might explain the better UIVA and UNVA compared with the current literature. The study of Cochener²⁰ and that of Ganesh et al.²⁵ were the only ones aiming for micromonovision with comparable MRSE outcomes. They found a slightly worse UDVA, UIVA (at 60 cm and 70 cm), and UNVA compared with our study. Ganesh et al.²⁵ reported a total spectacle independence of 84%. Cochener²⁰ noted that 19% of patients with a micromonovision target still needed additional reading spectacles for specific tasks, whereas 28% of patients with a bilateral emmetropic target needed additional reading spectacles. In our study, total spectacle independency was 64%, and only 21% of patients needed spectacle correction for longer than 1 hour a day. Only a few studies reported incidences of halos and glare. Monaco et al.²² showed that around 95% of patients experienced any type of halos, and 20% of patients experienced disabling halos. In terms of glare, they reported an

incidence of 90% of any form of glare, with 12% of patients experiencing disabling glare. Cochener²⁰ reported only 3% to 4% of patients with disabling halos and 1% to 2% of patients with disabling glare. Compared with our results, the percentage of disabling halos was comparable to the study of Monaco et al.²² The incidence of disabling glare was within 7% in the range of both studies.^{20,22}

Table 5 provides an overview of the currently available prospective case series and randomized controlled trials evaluating the AT LISA tri 839MP IOL.^{18,27–37} In terms of our primary outcome, several studies reported UIVA at 66 cm.^{18,27,28,37} In the present study, we found a slightly better mean UIVA of 0.01 logMAR compared with a mean UIVA ranging from 0.04 to 0.23 logMAR in the available literature. Furthermore, most studies investigated the UIVA at 80 cm, where some studies showed a better UIVA compared with the UIVA at 66 cm. This might indicate that the ideal intermediate distance is slightly further from the object compared with the used measurement distance for intermediate vision in our study. In terms of UDVA (4 m), previous studies showed comparable results (ranging from 0.05 to -0.06 logMAR) to our findings (mean UDVA -0.05 logMAR). However, for the near distance, a wider range was reported (0.01 to 0.27 logMAR). For UNVA, we found a mean UNVA of 0.04 ± 0.07 logMAR, which is better compared with most clinical studies. The reported spectacle independence rates after bilateral implantation of the AT LISA tri 839MP ranged from 50 to 100%. Our results showed a total spectacle independency of 54%. However, only 15% of patients needed spectacles for longer than 1 hour a day. With respect to optical phenomena, previous studies showed an incidence of 60 to 84% of any type of halos and an occurrence of 7% to 25% of disabling halos. In terms of glare, 28% to 50% of patients

Table 5. Continued.

UNVA		Halos (%)		Glare (%)		Total Spectacle Independence (%)
Distance (cm)	LogMAR	Any	Disabling	Any	Disabling	
40	0.20 ± 0.12	NA	NA	NA	NA	NA
40	0.27 ± 0.15	NA	NA	NA	NA	NA
40	0.27 ± 0.15	NA	NA	NA	NA	NA
40	0.01	NA	NA	NA	NA	50
40	0.13 ± 0.05	NA	7	NA	7	100
40	0.15 ± 0.14	80	25	41	6	>90
40	0.04 ± 0.10	60	NA	28	NA	88
40	0.05 ± 0.08	NA	NA	NA	NA	≤92
40	0.12 ± 0.12	NA	NA	NA	NA	NA
40	0.12 ± 0.12	NA	NA	NA	NA	NA
40	0.18 ± 0.05	NA	NA	NA	NA	<76
40	0.11 ± 0.15	NA	NA	NA	NA	NA
40	0.11 ± 0.15	NA	NA	NA	NA	NA
40	0.18 ± 0.05	70	NA	50	NA	67
40	0.11 ± 0.11	84	NA	40	NA	88
33	0.21 ± 0.15	NA	NA	NA	NA	NA

experienced any form of glare, whereas 6% to 7% reported disabling glare complaints. Compared with our results, we see a higher incidence of disabling halos (39% of patients) and a comparable incidence of disabling glare (8% of patients).

In the current study, we used the SRD to test the functional reading ability after bilateral implantation of the TECNIS Symphony IOL or the AT LISA tri 839MP IOL. We used this device to test the visual acuity at 40 cm and 66 cm and at the preferred patient distance. Furthermore, the mean number of words per minute was reported. We found no significant differences between both groups in the words per minute at any distance. Notably, the preferred reading distance at the intermediate distance in the AT LISA tri 839MP group was on average larger compared with the initial tested intermediate distance of 66 cm. These findings combined with the finding of better UIVA at 80 cm in the literature suggest that the ideal intermediate reading distance for the AT LISA tri 839MP is somewhere between 70 cm and 80 cm. When we compare the mean UIVA and UNVA obtained with the reading charts and the SRD, we see some differences. Whereas the AT LISA tri 839MP group had a better, however not significantly different, UNVA compared with the Symphony group using the reading charts, the SRD showed a comparable mean UNVA of 0.08 logMAR for both groups. In contrast to the UNVA, both groups scored worse at the UIVA using the SRD compared with the reading charts. The slight difference between both groups remained stable compared with the difference measured with the reading charts.

Mesopic conditions are known to be a major factor, which may decrease visual acuity after bilateral implantation of a trifocal or extended depth-of-focus (EDOF) IOL. In the current study, we saw a significant decrease in visual

acuity at all distances under mesopic conditions compared with photopic conditions for both groups. No statistically significant differences were seen comparing contrast sensitivity either under photopic or mesopic conditions, between groups. Furthermore, no differences were seen under mesopic conditions between both groups at any distance using reading charts or the SRD.

One of the limitations of the current study is the intraoperative astigmatism correction. Incisions on the steep axis or femtosecond laser-assisted arcuate incisions were performed preoperatively when indicated to correct preexisting corneal astigmatism. However, a total of 8% and 11% of eyes in the AT LISA tri 839MP and Symphony groups, respectively, had a residual cylinder of 1.5 D or more. Furthermore, the chosen intermediate distance of 66 cm is uncommon compared with the current literature. Therefore, a good comparison between previous studies and the current data cannot be done. In addition, the AT LISA tri 839MP IOL is designed for an intermediate vision at 80 cm. However, we believe that 66 cm might be a more commonly used working distance compared with the 80 cm used in previous studies. Another limitation is the lack of objective (optical bench) and psychophysical quantification of halos in this study. With regard to optical side effects, previous optical bench experiments showed a larger halo with 2 concentric rings (an outer, low-intensity ring and a small, high-intensity inner one) around the image of the pinhole for trifocal IOLs compared with bifocal IOLs.⁴ EDOF IOLs have fewer diffractive rings than trifocal IOLs. Yoo et al.³⁸ showed in their optical bench study that the halo pattern of these EDOF IOLs was similar to that found in the monofocal IOL. However, another in vitro study showed halos with comparable intensities for EDOF, bifocal and trifocal IOLs.³⁹ In the present study, the sample size

was not powered for the secondary outcomes, such as halos and glare. Finally, although monovision was used for the Symphony group, no monocular performance or stereoacuity was measured. In respect to stereovision, we have not received subjective complaints of the patients.

In conclusion, the current study showed that bilateral implantation of both the TECNIS Symphony IOL and the AT LISA tri 839MP IOL results in good binocular uncorrected visual acuity at far, intermediate, and near distances. Targeting micromonovision when implanting the TECNIS Symphony IOL could be used to improve the UNVA and UIVA compared with targeting emmetropia in both eyes. Around 80% of patients in both groups were total spectacle independent or needed spectacles less than 1 hour a day. Mesopic conditions have an inadvertent effect on visual acuity at all distances for both IOL designs. The less common photopic phenomenon in both groups was glare, with only a low incidence of disabling amounts of glare. Disabling halos was seen in twice as many patients after bilateral AT LISA tri 839MP IOL implantation compared with bilateral Symphony IOL implantation; however no statistically significant difference was found. The functional reading ability was comparable between both groups. Nevertheless, more than 90% of patients would recommend the implanted IOL to family and friends.

Based on the current results, we can conclude that the TECNIS Symphony IOL is a good alternative to achieve postoperative spectacle independence with minimal use of additional reading spectacles in 20% of cases.

WHAT WAS KNOWN

- Trifocal intraocular lenses (IOLs) have the ability to increase postoperative spectacle independence for near, intermediate, and far distances compared with monofocal and bifocal IOLs.

WHAT THIS PAPER ADDS

- The Symphony Extended Range of Vision IOL, applied as micromonovision, improved intermediate vision further without significantly compromising reading ability or increasing optical side effects.

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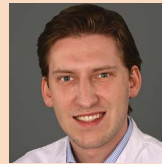
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- A. ClinicalTrials.gov Identifier: NCT03117426
- B. <https://www.surgical.jnjvision.com/iols/extended-depth-of-focus/tecnis-symfony#enhanced-functionality>

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