Int Ophthalmol (2021) 41:3675–3686
https://doi.org/10.1007/s10792-021-01925-8

ORIGINAL PAPER

# Clinical outcome comparison: bilateral trifocal vs. mix–match extended depth of focus and trifocal intraocular lenses

**Banu Acar · Burcu Nurozler Tabakci**

Received: 15 December 2020 / Accepted: 19 June 2021 / Published online: 27 June 2021


**Abstract**

*Purpose* To analyze the visual outcomes, contrast sensitivity (CS), and patient satisfaction differences between the bilateral implantation of a trifocal intraocular lens (IOL) and the mix–match implantation of an extended-depth-of-focus (EDOF) IOL and a diffractive trifocal IOL.

*Methods* A total of 20 patients who underwent bilateral implantation of AT LISA tri 839MP (Group 1) and 20 patients who had a mix–match implantation of AT LARA 829MP in the dominant eye and AT LISA tri 839MP in the nondominant eye (Group 2) were evaluated. Uncorrected distance (4 m), intermediate (60 cm and 80 cm), and near (40 cm) visual acuity, as well as CS, defocus curve, and responses to the patient questionnaires, were evaluated.

*Results* Eighty eyes of 40 patients were included. Uncorrected distance and near visual outcomes were similar between the groups ($p > 0.05$). Group 2 showed significantly better intermediate visual outcomes at 60 cm and 80 cm than Group 1 ($p < 0.05$). Group 2 showed significantly better CS outcomes (photopic and mesopic) than Group 1 ($p < 0.05$). There was no significant difference between the groups regarding defocus curves from + 0.00 D to − 2.00 D, but a significant difference was shown from − 2.00 D to − 4.00 D. Patients' satisfaction was significantly higher in Group 2 for driving at night ($p < 0.05$).

*Conclusions* Both groups showed an effective visual performance. Group 2 exhibited better photopic and mesopic CS. The combination of EDOF and trifocal IOL seems to be a good option with a comfortable vision at all distances and less adverse visual phenomena.

**Keywords** Enhanced depth of focus · Intraocular lens · Trifocal · Cataract surgery · Photic phenomena

B. Acar
Ophthalmology Department, Faculty of Medicine, Biruni University, Istanbul, Turkey

B. Nurozler Tabakci (✉)
Ophthalmology Department, Basaksehir Cam and Sakura City Hospital, Istanbul, Turkey
e-mail: burcunurtabakci@gmail.com

## Introduction

Cataract surgery has evolved into a refractive procedure in recent years. Multifocal intraocular lens (MFIOL) implantation has become a common approach that enhances visual outcomes after cataract surgery. Advances in MFIOL technology make the surgery more customized and raised the patient's expectations about their vision at all viewing distances.

Technological developments increase the demand for uninterrupted intermediate vision. Bifocal IOLs

perform satisfactory results in near and far vision with different near addition options, but they are insufficient for intermediate distances [1]. Trifocal IOLs provide a third focal point for intermediate distances in addition to bifocal IOLs [2, 3]. The previous literature has shown that trifocal IOLs improve mid-range vision quality as well as unwanted optical phenomena [4]. Extended-depth-of-focus (EDOF) IOLs were developed with a distinctive diffractive pattern with an achromatic design to overcome the photic phenomena with trifocal IOLs. EDOF IOL technology offers an uninterrupted range of vision. EDOF IOLs showed similar results in terms of uncorrected far and intermediate visual outcomes compared with trifocal IOLs [5]. However, patients who were implanted with EDOF IOLs showed more spectacle dependence for near vision than trifocal IOLs [6]. In this study, an EDOF IOL was combined with a trifocal IOL for better functional near vision with decreased photic phenomena.

The aim of this study was to evaluate visual outcomes, contrast sensitivity (CS), and patient satisfaction differences between the bilateral implantation of a commonly used diffractive trifocal IOL and the mix–match implantation of an EDOF lens in the dominant eye and a diffractive trifocal IOL in the nondominant eye. In light of the previous literature, our primary focus was that whether blended implantation of an EDOF IOL and a diffractive trifocal IOL could overcome visual disturbances such as halo and glare, especially under mesopic light conditions compared with bilateral implantation of trifocal IOLs. The current study also aimed to investigate whether the implantation of an EDOF IOL in the patient's dominant eye could improve intermediate visual outcomes without disturbing near vision and whether the patients with blended implantation of an EDOF IOL and a diffractive trifocal IOL could achieve more satisfactory visual outcomes that affect the quality of life.

## Methods

### Study design

This study was a retrospective, nonrandomized comparative study. The study was conducted at the Batigöz Eye Hospital in Istanbul, from June 2016 to May 2018. The current study was completed in accordance with the tenets of Declaration of Helsinki and was approved by the Ethical Committee of Biruni University, Istanbul, Turkey (2020/42-14). This study included consecutive cases who had bilateral implantation of a trifocal IOL or combined implantation of an EDOF IOL in the dominant eye and a trifocal IOL in the nondominant eye after bilateral cataract surgery. Informed written consent was obtained from all patients before surgery.

### Participants

Patients who had asked for presbyopia correction after phacoemulsification surgery were included in the study. The study consisted of 80 eyes of 40 patients with bilateral implantation of AT LISA tri 839 MP IOL or blended implantation of AT LARA 829 MP IOL and AT LISA tri 839 MP IOL by a single surgeon. All patients underwent a comprehensive preoperative ophthalmological examination, comprising slit-lamp biomicroscopy, Goldmann tonometry, and biometry (IOL Master v.4.3, Carl Zeiss Meditec). Patients were excluded from the study if they had any pathology of the cornea, retina, or optic nerve, as well as corneal astigmatism greater than 0.75 D, marked irregular corneal astigmatism, amblyopia, uveitis, and history of ocular surgery. Participants were informed about the possible advantages and disadvantages of bilateral trifocal IOL implantation or blended implantation of an EDOF with a trifocal IOL. The aimed postoperative refraction was emmetropia in both groups.

### Multifocal IOLs

In the current study, patients of Group 1 were bilaterally implanted with a trifocal IOL (AT LISA tri 839 MP). AT LISA tri 839MP (Carl Zeiss Meditec) is a diffractive trifocal IOL made of hydrophilic acrylic material. This IOL has a trifocal part in the central 4.3 mm, which provides a near addition of + 3.33 D and an intermediate addition of + 1.66 D in the IOL plane. AT LARA 829MP (Carl Zeiss Meditec) is an EDOF IOL with a unique diffractive optical design that provides a wider range of focus and a patented smooth surface design with shallower angles, which is different from conventional diffractive lens designs. This technology minimizes light scattering and provides visual comfort at night.

### Surgical technique

All surgical procedures were completed by the same practicing surgeon (BA) using a standard technique of sutureless micro coaxial 1.8 mm phacoemulsification. Tunnel incisions were made at the steep axis of the cornea. After a 5.0–5.5 mm capsulorhexis creation and phacoemulsification, the IOLs were inserted into the capsular bag using the BLUEMIXS 180 injector (Carl Zeiss Meditec) through the tunnel incision. All patients used a combined eyedrop including antibiotic and steroid agents after surgery.

### Outcome measures

All patients underwent examinations of uncorrected distance visual acuity (UDVA) at 4 m, uncorrected intermediate visual acuity (UIVA) at 60 cm and 80 cm, and uncorrected near visual acuity (UNVA) at 40 cm, refractive status, slit-lamp examination, Goldmann tonometry, and biometry (IOL Master v.4.3., Carl Zeiss Meditec AG, Germany) during the preoperative and six-month postoperative visits. Binocular defocus curves were acquired by adding trial lenses from + 2.5 D to − 4.00 D (in 0.50 D steps) over the best-corrected distance refraction. The CSV-1000E chart (Vector Vision, Ohio, USA) was used to evaluate CS. CS was evaluated under photopic and mesopic conditions at the spatial frequencies of 3, 6, 12, and 18 cycles/degree (cpd).

Subjective quality of vision was evaluated using the 14-item Visual Function Questionnaire (VFQ-14). Each item was scaled according to the degree of difficulty of different activities: 4 points (no difficulty), 3 points (a little difficulty), 2 points (a moderate amount of difficulty), 1 point (a great deal of difficulty), and 0 point (unable to do the activity). The presence of halo and glare was assessed using a Likert scale (0–3). The frequency of photopic phenomenon (0 = never, 3 = very often), the severity of photopic phenomenon (0 = not at all, 3 = severe), and how bothersome the photopic phenomenon (0 = not at all, 3 = very) were assessed.

### Statistical analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences version 20.0 (SPSS Inc., Chicago, IL, USA). The Student's t test was performed for the comparisons of parametric data. The Mann–Whitney $U$ test was used to analyze the differences between independent groups for nonparametric analysis. The Chi-square test was used for comparisons between categorical variables, and a $p$-value of $< 0.05$ was considered statistically significant.

## Results

The current study comprised 80 eyes of 40 patients who had bilateral cataract surgery. Twenty patients who had bilateral implantation of AT LISA tri 839MP were considered as Group 1, and 20 patients who had blended implantation of AT LARA 829MP in the dominant eye and AT LISA tri 839MP in the nondominant eye were considered as Group 2. Patients' baseline characteristics are reported in Table 1. There were no statistically significant differences in patients' baseline characteristics between the two groups regarding age ($p = 0.5$), gender ($p = 0.5$), axial length ($p = 0.3$), keratometry ($p = 0.3$), and anterior chamber depth ($p = 0.4$), UDVA ($p = 0.1$), corrected distance visual acuity (CDVA) ($p = 0.2$), UIVA ($p = 0.3$), distance-corrected intermediate visual acuity (DCIVA) ($p = 0.5$), UNVA ($p = 0.3$), and distance-corrected near visual acuity (DCNVA) ($p = 0.5$).

Preoperative and postoperative mean refractive errors are summarized in Table 2. The differences between preoperative and postoperative refractive errors were not significantly different between the groups ($p > 0.05$). Binocular visual acuity outcomes 6 months after cataract surgeries are summarized in Table 3. The differences between the groups regarding UDVA ($p = 0.4$) and UNVA ($p = 0.09$) were not statistically significant. Group 2 showed better UIVA outcomes at both 60 cm and 80 cm than Group 1 ($p < 0.01$).

Group 2 showed significantly better CS outcomes (photopic and mesopic) than Group 1, for all spatial frequencies evaluated ($p < 0.05$) (Fig. 1). There was no statistically significant difference between the groups regarding defocus curves from + 0.00 D to − 2.00 D, but showed a significant difference was found from − 2.00 D to − 4.00 D (Fig. 2).

The frequency and severity of photopic phenomena are summarized in Table 4. The frequency of halo and

**Table 1** Baseline patient characteristics of groups

| | Bilateral AT LISA ($n$ = 20) | Blended AT LISA-AT LARA ($n$ = 20) | $p$-value |
|---|---|---|---|
| Age (years) | 64.5 ± 5.7 | 66.1 ± 4.2 | 0.596 |
| Gender (female/male) | 12/8 | 10/10 | 0.525 |
| Axial length (mm) | 23.8 ± 1.65 | 24.1 ± 1.14 | 0.325 |
| Spherical equivalent (D) | 0.65 ± 3.75 | 0.58 ± 3.94 | 0.295 |
| Mean keratometry (D) | 43.75 ± 1.55 | 43.42 ± 1.35 | 0.320 |
| Anterior chamber depth (mm) | 3.21 ± 0.26 | 3.26 ± 0.25 | 0.436 |
| UDVA (logMAR) | 1.15 ± 0.28 | 1.22 ± 0.35 | 0.186 |
| CDVA (logMAR) | 0.55 ± 0.60 | 0.52 ± 0.71 | 0.224 |
| UIVA (logMAR) | 1.20 ± 0.36 | 1.25 ± 0.62 | 0.352 |
| DCIVA (logMAR) | 0.44 ± 0.22 | 0.46 ± 0.19 | 0.558 |
| UNVA (logMAR) | 1.28 ± 0.55 | 1.36 ± 0.42 | 0.335 |
| DCNVA (logMAR) | 0.38 ± 0.25 | 0.40 ± 0.18 | 0.524 |

*CDVA* corrected distance visual acuity, *DCIVA* distance-corrected intermediate visual acuity, *DCNVA* distance-corrected near visual acuity, *D* diopter, *logMAR* logarithm of the minimum angle of resolution, *mm* milimeter, *UDVA* uncorrected distance visual acuity, *UIVA* uncorrected intermediate visual acuity, *UNVA* uncorrected near visual acuity

glare was significantly different between the groups ($p$ = 0.035, $p$ = 0.011, respectively). The severity of photic phenomena was significantly different between the groups, regarding halo ($p$ = 0.003) and glare ($p$ = 0.004). The difference between patient responses to "how disturbing/troublesome is the photic phenomena" was significantly different regarding halo ($p$ = 0.005) and glare ($p$ = 0.007).

The results of VFQ-14 Questionnaire at 6 months are summarized in Table 5. The average total scores (sum of all questions) were 52.8 in Group 1 and 53.5 in Group 2, over a maximum score of 56 for the whole study. When item-based responses were considered, 82% (232/240) and 86% (241/280) of total questions were scored 4 (no difficulty) in Group 1 and Group 2, respectively, indicating a higher satisfaction in Group 2. However, when item-based responses were compared, only the satisfaction about driving at night was significantly different between the groups ($p$ = 0.003).

## Discussion

Recently, advances in MFIOL technology have produced more satisfactory visual outcomes after cataract surgery and shown a vital impact on the patients' quality of life. Trifocal IOLs have been introduced with three focal spots that improve UIVA as well as uncorrected near and distance vision [1–3]. Previous studies have reported effective visual outcomes at near, intermediate, and far distances with the bilateral implantation of different commercial trifocal IOLs [1, 3, 7, 8]. However, photic phenomena are an important cause that compromises patients' satisfaction after the implantation of trifocal IOLs [4, 9]. The EDOF IOL design provides a continuous range of uncorrected vision at different distances while minimizing the incidence of dysphotopsia [10]. The blended implantation of different multifocal IOLs is another option, which has been used for a long time to achieve better binocular visual outcomes at a wide range of distances [11].

In this study, UDVA, UIVA at 60 cm, UIVA at 80 cm, and UNVA logMAR values were assessed as 0.03 ± 0.05, 0.16 ± 0.14, 0.12 ± 0.1, 0.03 ± 0.08 in Group 1, and 0.04 ± 0.06, 0.05 ± 0.08, 0.06 ± 0.08, 0.07 ± 0.1 in Group 2, respectively. The results of our study show that both the bilateral implantation of AT LISA trifocal IOL and the blended implantation of AT LISA trifocal and AT LARA EDOF IOL options provided independence from spectacles by achieving postoperative emmetropia. Both strategies were efficient in achieving adequate UDVA, UIVA, and UNVA; however, the blended implantation of trifocal and EDOF IOL showed better UIVA outcomes at distances of 60 cm and 80 cm. These findings show

**Table 2** Preoperative and postoperative refractive status

| | Bilateral AT LISA | | AT LISA-AT LARA | | *p* value |
|---|---|---|---|---|---|
| | Preop | Postop | Preop | Postop | |
| Sphere (D) | 0.50 ± 2.05 (− 4.00, 2.00) | 0.14 ± 0.40 (− 0.50, 1.00) | 0.62 ± 2.65 (− 3.00, 3.50) | 0.20 ± 0.36 (− 0.75, 1.00) | 0.450 |
| Cylinder (D) | − 0.25 ± 0.85 (− 0.75, 0.75) | − 0.50 ± 0.35 (− 0.75, 0.50) | − 0.45 ± 0.71 (− 0.75, 0.75) | − 0.55 ± 0.54 (− 0.75, 0.75) | 0.612 |
| Spherical Equivalant (D) | 0.45 ± 3.45 (− 6.00, 5.00) | − 0.25 ± 0.50 (− 1.25, 0.75) | 0.72 ± 3.89 (− 5.00, 4.50) | − 0.18 ± 0.44 (− 1.00, 1.00) | 0.187 |

*D* diopter

the superiority of EDOF IOLs over trifocal IOLs for an intermediate vision.

Table 6 summarizes the clinical outcomes of previous studies after the bilateral implantation of trifocal and EDOF IOLs [12–18]. Webers et al. compared the UIVA outcomes of 15 patients who were bilaterally implanted with AT LISA trifocal IOL and 15 patients who were bilaterally implanted with Symfony EDOF IOL in a randomized prospective study. They concluded that there was no significant difference with regard to UNVA and UDVA; however, UIVA was significantly better in the Symfony group [16]. Singh et al. compared 160 eyes of 80 patients who were bilaterally implanted with FineVision Micro F trifocal IOL or TECNIS Symfony EDOF IOL. They concluded that the binocular UNVA was significantly better in trifocal IOL as compared with the EDOF IOL [17]. Tarib et al. compared the patients who had bilateral implantation of an EDOF IOL ($n$ = 40) and the patients who had the same EDOF IOL in the dominant eye and a trifocal IOL in the nondominant eye ($n$ = 40) after 3 months of bilateral cataract surgery. The DCNVA was significantly better in a mixed group; however, there was no significant difference with regard to UDVA, UIVA, and UNVA between the groups [18].

In this study, the best values of photopic CS were established at 6 cpd, and the best levels of mesopic CS were established at 3 cpd for both the groups. Group 2 showed significantly better photopic and mesopic CS values than Group 1 for all evaluated spatial frequencies. Ganesh et al. followed 25 patients who had bilateral implantation of AT LISA 839 trifocal IOL for 12 months. They reported a slight reduction in CS at 12 and 18 cpd, but there was no statistically significant difference. They concluded that the CS values at 12 months were comparable to the values at 1 month at all the spatial frequencies [19]. Poyales et al. concluded that CS was lower at 12 and 18 cpd than at than at 3 cpd and 6 cpd with bilateral implantation of AT LARA EDOF IOL [14]. Webers et al. compared the CS between bilateral implantation of AT LISA 839 MP trifocal IOL and bilateral implantation of TECNIS Symfony EDOF IOL and concluded that there was no statistically significant difference between the groups either under photopic or mesopic conditions. However, visual acuity at all the distances significantly reduced under mesopic conditions compared with photopic conditions for both the groups [16]. Escandon-Garcia et al. compared the bilateral implantation of FineVision trifocal IOL ($n$ = 23), Panoptix trifocal IOL ($n$ = 7), and Symfony EDOF IOL ($n$ = 15). They reported that CS values of these IOLs were higher than the inferior limit of normality at 3, 12, and 18 cpd and dropped below the inferior limit of normality at 6 cpd. There was no statistically significant difference between the groups at evaluated spatial frequencies under photopic and mesopic conditions [20]. These findings suggest that the blended implantation of EDOF and trifocal IOL provides significantly better CS outcomes.

In this study, the defocus curves were similar between the groups from + 0.00 D to − 2.00 D, but showed a significant difference from − 2.00 D to − 4.00 D. In a previous study, after the bilateral implantation of AT LISA trifocal IOL, the best visual acuity outcomes were achieved at 0.00 D and − 2.00 D. They also reported that the defocus curve was in the zone of 0.1 logMAR or better in the intermediate zone [19]. Poyales et al. showed that the visual acuity

**Table 3** Binocular visual acuity outcomes of groups

| | Bilateral AT LISA Mean ± SD (min–max) | Blended AT LISA-AT LARA Mean ± SD (min–max) | *p*-value |
|---|---|---|---|
| UDVA | 0.03 ± 0.05 (− 0.10, 0.2) | 0.04 ± 0.06 (0.00, 0.2) | 0.496 |
| CDVA | − 0.02 ± 0.04 (− 0.12, 0.1) | − 0.03 ± 0.05 (− 0.10, 0.15) | 0.574 |
| UIVA (60 cm) | 0.16 ± 0.14 (0.00, 0.2) | 0.05 ± 0.08 (0.00, 0.12) | < 0.001* |
| DCIVA (60 cm) | 0.09 ± 0.1 (0.00, 0.14) | 0.07 ± 0.08 (0.00, 0.08) | 0.272 |
| UIVA (80 cm) | 0.12 ± 0.1 (0.00, 0.2) | 0.06 ± 0.08 (0.00, 0.15) | < 0.001* |
| DCIVA (80 cm) | 0.05 ± 0.09 (0.00, 0.1) | 0.04 ± 0.08 (0.00, 0.3) | 0.216 |
| UNVA (40 cm) | 0.03 ± 0.08 (− 0.10, 0.20) | 0.07 ± 0.1 (0.00, 0.3) | 0.096 |
| DCNVA (40 cm) | 0.01 ± 0.05 (− 0.10, 0.1) | 0.02 ± 0.08 (− 0.10, 0.15) | 0.431 |

*CDVA* corrected distance visual acuity, *DCIVA* distance-corrected intermediate visual acuity, *DCNVA* distance-corrected near visual acuity, *min* minimum, *max* maximum, *SD* standard deviation, *UDVA* uncorrected distance visual acuity, *UIVA* uncorrected intermediate visual acuity, *UNVA* uncorrected near visual acuity

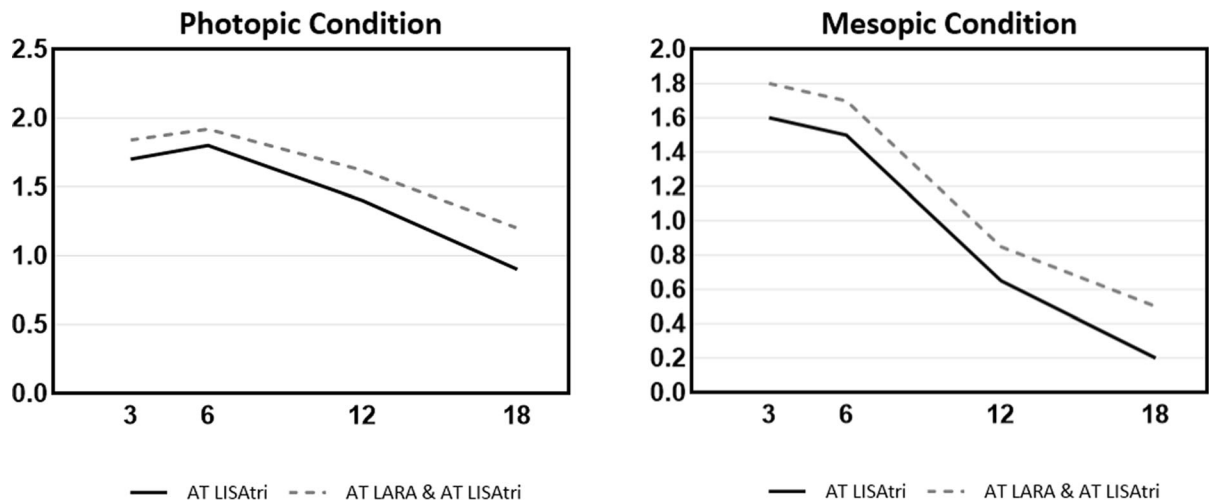


**Fig. 1** Mean 6-month postoperative contrast sensitivity function of groups

progressively decreased when the level of negative defocus increased up to − 2.00 D in patients with bilateral AT LARA IOL implantation at the postoperative one-month visit [14].

The perceptions of dysphotopsia (halo and glare) were evaluated six months after surgery by using a Likert scale in this study. Two patients reported the frequency of halo as "very often" in Group 1. The frequency of halo and glare was significantly different between the groups. Two patients scaled the severity of halo as "severe" in Group 1. The severity of photic phenomena was statistically different between the groups, regarding halo and glare. One patient reported that the halos were "very" disturbing in Group 1. The

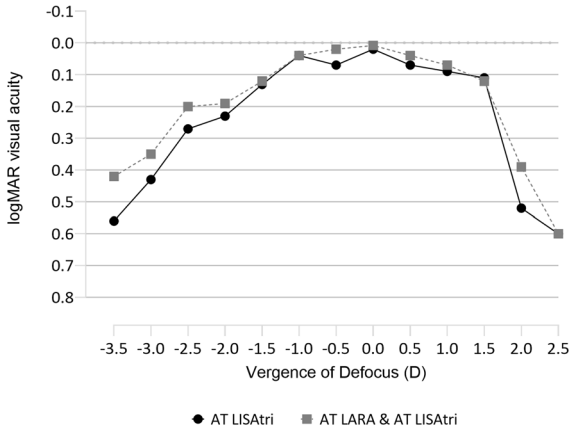


**Fig. 2** Defocus curves of groups

difference between the patient responses to "how disturbing/troublesome the photic phenomena" was statistically significant regarding halo and glare. Law et al. concluded that the halos associated with the bilateral implantation of AT LISA trifocal IOLs were well tolerated and that the perception of halo and glare decreased from 80% (halo) and 73.3% (glare) at one month to 40% (halo) and 13.3% (glare) at six months after the surgery [21]. Our findings suggest that the blended implantation of EDOF and trifocal IOLs reduces the frequency and severity of photic phenomena, which is less troublesome compared with the bilateral implantation of trifocal IOLs.

In our study, the VFQ 14 questionnaire was evaluated six months after surgery. When the item-based responses were considered, 82% (232/280) and 86% (241/280) of total questions were scored 4 (no difficulty) in Group 1 and Group 2, respectively, thereby indicating a higher satisfaction in Group 2. Two patients reported a great deal of difficulties while driving at night. Patients' satisfaction was significantly higher for driving at night in Group 2. This result is consistent with the lower severity and

**Table 4** Presence of photic phenomena

| | Halo | | Glare | |
|---|---|---|---|---|
| | Bilateral AT LISA (*n*) | AT LISA-AT LARA (*n*) | Bilatarel AT LISA (*n*) | AT LISA-AT LARA (*n*) |
| Frequency of photic phenomena | | | | |
| Never | 3 | 8 | 9 | 17 |
| Occasionally | 11 | 11 | 8 | 2 |
| Quiet often | 4 | 2 | 3 | 1 |
| Very often | 2 | 0 | 0 | 0 |
| Severity of photic phenomena | | | | |
| Not at all | 5 | 15 | 8 | 17 |
| Mild | 9 | 3 | 7 | 2 |
| Moderate | 4 | 2 | 5 | 1 |
| Severe | 2 | 0 | 0 | 0 |
| How disturbing/troublesome the photic phenomena | | | | |
| Not at all | 7 | 15 | 8 | 16 |
| Mild | 5 | 4 | 9 | 4 |
| Moderate | 7 | 1 | 3 | 0 |
| Severe | 1 | 0 | 0 | 0 |

**Table 5** Results of VFQ-14 Questionnaire at the postoperative 6 months

| Questions | Bilateral AT LISA Categories of responses (%) | | | | | | Mix–match Categories of responses (%) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Score Mean ± SD | No difficulty *n* (%) | A little of difficulty *n* (%) | A moderate amount of difficulty *n* (%) | A great deal of difficulty *n* (%) | Unable to do *n* (%) | Score Mean ± SD | No difficulty *n* (%) | A little of difficulty *n* (%) | A moderate amount of difficulty *n* (%) | A great deal of difficulty *n* (%) | unable to do *n* (%) | *p* value |
| Reading small print | 3.70 ± 0.57 | 15 (75%) | 4 (20%) | 1 (5%) | 0 | 0 | 3.55 ± 0.68 | 13 (65%) | 5 (25%) | 2 (10%) | 0 | 0 | 0.469 |
| Reading normal newsprint | 3.90 ± 0.30 | 18 (90%) | 2 (10%) | 0 | 0 | 0 | 3.90 ± 0.30 | 18 (90%) | 2 (10%) | 0 | 0 | 0 | 1.0 |
| Reading large newsprint | 3.95 ± 0.22 | 19 (95%) | 1 (5%) | 0 | 0 | 0 | 3.95 ± 0.22 | 19 (95%) | 1 (5%) | 0 | 0 | 0 | 1.0 |
| Recognizing faces at a distance | 3.85 ± 0.48 | 18 (90%) | 1 (5%) | 1 (5%) | 0 | 0 | 3.85 ± 0.48 | 18 (90%) | 1 (5%) | 1 (5%) | 0 | 0 | 1.0 |
| Going downstairs | 3.95 ± 0.22 | 19 (95%) | 1 (5%) | 0 | 0 | 0 | 3.95 ± 0.22 | 19 (95%) | 1 (5%) | 0 | 0 | 0 | 1.0 |
| Reading street signs | 3.95 ± 0.22 | 19 (95%) | 1 (5%) | 0 | 0 | 0 | 3.95 ± 0.22 | 19 (95%) | 1 (5%) | 0 | 0 | 0 | 1.0 |
| Sewing, doing delicate manual work | 3.60 ± 0.68 | 14 (70%) | 4 (20%) | 2 (10%) | 0 | 0 | 3.50 ± 0.76 | 13 (65%) | 4 (20%) | 3 (15%) | 0 | 0 | 0.694 |
| Reading mail, bills accurately | 3.80 ± 0.52 | 17 (85%) | 2 (10%) | 1 (5%) | 0 | 0 | 3.80 ± 0.52 | 17 (85%) | 2 (10%) | 1 (5%) | 0 | 0 | 1.0 |
| Playing cards | 3.90 ± 0.30 | 18 (90%) | 2 (10%) | 0 | 0 | 0 | 3.90 ± 0.30 | 18 (90%) | 2 (10%) | 0 | 0 | 0 | 1.0 |
| Going out to movies, plays, sporting events | 3.80 ± 0.52 | 17 (85%) | 2 (10%) | 1 (5%) | 0 | 0 | 3.80 ± 0.52 | 17 (85%) | 2 (10%) | 1 (5%) | 0 | 0 | 1.0 |
| Cooking | 3.90 ± 0.30 | 18 (90%) | 2 (10%) | 0 | 0 | 0 | 3.90 ± 0.30 | 18 (90%) | 2 (10%) | 0 | 0 | 0 | 1.0 |
| Watching tv | 3.75 ± 0.55 | 16 (80%) | 3 (15%) | 1 (5%) | 0 | 0 | 3.75 ± 0.55 | 16 (80%) | 3 (15%) | 1 (5%) | 0 | 0 | 1.0 |
| Driving on day | 3.75 ± 0.55 | 16 (80%) | 3 (15%) | 1 (5%) | 0 | 0 | 3.95 ± 0.22 | 19 (95%) | 1 (5%) | 0 | 0 | 0 | 0.150 |

**Table 5** continued

| Questions | Bilateral AT LISA Categories of responses (%) | | | | | | Mix–match Categories of responses (%) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Score Mean ± SD | No difficulty *n* (%) | A little of difficulty *n* (%) | A moderate amount of difficulty *n* (%) | A great deal of difficulty *n* (%) | Unable to do *n* (%) | Score Mean ± SD | No difficulty *n* (%) | A little of difficulty *n* (%) | A moderate amount of difficulty *n* (%) | A great deal of difficulty *n* (%) | unable to do *n* (%) | *p* value |
| Driving at night | 3.00 ± 1.02 | 8 (40%) | 6 (30%) | 4 (20%) | 2 (10%) | 0 | 3.80 ± 0.52 | 17 (85%) | 2 (10%) | 1 (5%) | 0 | 0 | 0.003 |

*SD* standard deviation

frequency of the photopic phenomena in Group 2. Law et al. evaluated 30 patients' satisfaction using a self-developed questionnaire after the bilateral implantation of AT LISA trifocal IOL. There was no difficulty observed for watching TV or driving. However, moderate difficulties were notified by a minimal percentage of patients for visual demands at near and intermediate distances, such as reading a newspaper or using a computer [21]. Kretz et al. presented that 96% of patients were able to complete their daily activities without any visual problem after the bilateral implantation of AT LISA trifocal IOL [13]. After the bilateral implantation of AT LARA EDOF IOL, 95% of the patients notified that they would prefer to have the same surgery with the AT LARA implantation again, and 11% of patients needed spectacle correction for prolonged near visual tasks [14]. These findings suggest that the blended implantation of EDOF and trifocal IOLs could overcome the difficulties while driving at night compared with the bilateral trifocal IOL implantation.

This study has some limitations. First, the reading speed, which is an important manifestation of functional near vision, was not analyzed in this study. Second, photic phenomena and patient satisfaction scores were evaluated at six months of surgery, which can be changed by time because of the neuroadaptation process. More importantly, this was a nonrandomized study.

In conclusion, the blended implantation of EDOF and trifocal IOL showed a significantly better binocular UIVA, significantly better photopic and mesopic CS values, higher satisfaction scores with reduced frequency and the severity of halo and glare compared with the bilateral implantation of trifocal IOLs. The blended implantation of trifocal IOLs and EDOF IOLs is promising treatment options for patients who want independence from spectacles for an intermediate vision without photic phenomena.

**Table 6** Clinical outcomes after binocular trifocal and EDOF IOLs implantation of previous studies

| Author (year) | Eyes | IOL | Follow-up (months) | logMAR UDVA | logMAR CDVA | logMAR UIVA | logMAR CIVA | logMAR UNVA | logMAR CNVA |
|---|---|---|---|---|---|---|---|---|---|
| Menucci et al. [12] | 42 | AT LISA tri 839MP | 3 | 0.00 ± 0.05 | 0.00 ± 0.05 | 0.11 ± 0.07<br>80 cm | – | 0.18 ± 0.05<br>40 cm | – |
| Kretz et al. [13] | 100 | AT LISA tri 839MP | 3 | 0.06 (− 0.10 to 0.30) | 0.04 (− 0.20 to 0.30) | 0.09 (− 0.10 to 0.30)<br>66 cm | – | 0.06 (− 0.10 o 0.30)<br>40 cm | – |
| Poyales et al. [14] | 38 | AT LARA 829 EDOF | 1 | 0.08 ± 0.10 | 0.00 ± 0.02 | – | 0.14 ± 0.07<br>80 cm | – | 0.30 ± 0.08 |
| Tarib et al. [15] | 14 | AT LARA 829 EDOF | 3 | − 0.03 ± 0.07 | − 0.04 ± 0.05 | – | 0.02 ± 0.12<br>80 cm<br>0.05 ± 0.10<br>60 cm | – | 0.32 ± 0.13 |
| Webers et al. [16] | 15<br>15 | AT LISA tri 839MP<br>Symfony EDOF IOL | 3 | − 0.05 ± 0.07<br>0.01 ± 0.12 | – | 0.01 ± 0.03<br>66 cm<br>− 0.02 ± 0.03<br>66 cm | – | 0.04 ± 0.07<br>40 cm<br>0.09 ± 0.05<br>40 cm | – |
| Singh et al. [17] | 80<br>80 | FineVision Micro F trifocal IOL<br>TECNIS Symfony EDOF IOL | 6 | 0.96 ± 0.06<br>Decimal<br>0.97 ± 0.12<br>Decimal | – | 0.79 ± 0.11<br>Decimal 60 cm<br>0.77 ± 0.13<br>Decimal 60 cm | – | 0.77 ± 0.16<br>Decimal<br>0.68 ± 0.12<br>Decimal | – |
| Tarib et al. [18] | 40<br>40 | AT LARA 829 EDOF<br>AT LARA 829 (dominant eye)<br>AT LISA 839MP (nondominant eye) | 3 | − 0.04 ± 0.07<br>0.03 ± 0.09 | − 0.04 ± 0.06<br>− 0.01 ± 0.07 | – | 0.07 ± 0.19<br>80 cm<br>0.24 ± 0.23<br>80 cm | 0.24 ± 0.17<br>40 cm<br>0.18 ± 0.10<br>40 cm | 0.32 ± 0.15<br>0.19 ± 0.07 |

*CDVA* corrected distance visual acuity, *CIVA* corrected intermediate visual acuity, *CNVA* corrected near visual acuity, *EDOF* extended depth of focus, *IOL* intraocular lens, *logMAR* logarithm of the minimum angle of resolution, *UDVA* uncorrected distance visual acuity, *UIVA* uncorrected intermediate visual acuity, *UNVA* uncorrected near visual acuity

**Authors' contributions** BA has participated in the design of the study, data collection, data analysis and interpretation, and critical revision. BNT has performed the data analysis, statistical analyses, and drafted the manuscript. All authors read and approved the final manuscript.

**Funding** The authors received no financial support for the research, authorship, and publication of this article.

**Availability of data and material** The data that support the findings of this study are available from authors.

**Declarations**

**Conflicts of interest** The authors declare that they have no conflict of interest.

**Ethical approval** The current study was completed in accordance with the tenets of Declaration of Helsinki and was approved by the Ethical Committee of Biruni University, Istanbul, Turkey (Approval Number: 2020/42-14).

**Consent to participate** This was a retrospective study. Informed written consent was obtained from all patients before surgery.

**Consent for publication** This was a retrospective study.

## References

1. Mojzis P, Kukuckova L, Majerova K, Liehneova K, Piñero DP (2014) Comparative analysis of the visual performance after cataract surgery with implantation of a bifocal or trifocal diffractive IOL. J Refract Surg 30:666–672
2. Mojzis P, Pena-Garcia P, Liehneova I, Ziak P, Alió JL (2014) Outcomes of a new diffractive trifocal intraocular lens. J Cataract Refract Surg 40:60–69
3. Voskresenskaya A, Pozdeyeva N, Pashtaev N, Batkov Y, Treushnicov V, Valentin CV (2010) Initial results of trifocal diffractive IOL implantation. Graefes Arch Clin Exp Ophthalmol 248:1299–1306
4. Vilar C, Hida WT, de Medeiros AL, Magalhães KRP, Tzelikis PFM, Chaves MAPD, Motta AFP, Carricondo PC, Alves MR, Nosé W (2017) Comparison between bilateral implantation of a trifocal intraocular lens and blended implantation of two bifocal intraocular lenses. Clin Ophthalmol 11:1393–1397
5. Cochener B, Boutillier G, Lamard M, Auberger-Zagnoli C (2018) A comparative evaluation of a new generation of diffractive trifocal and extended depth of focus intraocular lenses. J Refract Surg 34:507–514
6. Mencucci R, Favuzza E, Caporossi O, Savastano A, Rizzo S (2018) Comparative analysis of visual outcomes, reading skills, contrast sensitivity, and patient satisfaction with two models of trifocal diffractive intraocular lenses and an extended range of vision intraocular lens. Graefes Arch Clin Exp Ophthalmol 256:1913–1922
7. Cochener B, Vryghem J, Rozot P, Savastano A, Rizzo S (2014) Clinical outcomes with a trifocal intraocular lens: a multicenter study. J Refract Surg 30:762–768
8. Kohnen T, Titke C, Bohm M (2016) Trifocal intraocular lens implantation to treat visual demands in various distances following lens removal. Am J Ophthalmol 161:71–77
9. de Silva SR, Evans JR, Kirthi V, Ziaei M, Leyland M (2016) Multifocal versus monofocal intraocular lenses after cataract extraction. Cochrane Database Syst Rev 12:CD003169
10. Kohnen T, Suryakumar R (2020) Extended depth-of-focus technology in intraocular lenses. J Cataract Refract Surg 46:298–304
11. Breyer DRH, Kaymak H, Ax T, Kretz FTA, Auffarth GU, Hagen PR (2017) Multifocal intraocular lenses and extended depth of focus intraocular lenses. Asia Pac J Ophthalmol 4:339–349
12. Mencucci R, Favuzza E, Caporossi O, Rizzo S (2017) Visual performance, reading ability and patient satisfaction after implantation of a diffractive trifocal intraocular lens. Clin Ophthalmol 11:1987–1993
13. Kretz FTA, Choi CY, Müller M, Gerl M, Gerl RH, Auffarth GU (2016) Visual outcomes, patient satisfaction, and spectacle independence with a trifocal diffractive intraocular lens. Korean J Ophthalmol 30(3):180–191
14. Poyales F, Garzón N, Poyales C, Poyales B (2018) Clinical outcomes with a new model of extended depth of focus intraocular lens. Open J Ophthalmol 8:161–170
15. Tarib I, Kasier I, Herbers C, Hagen P, Breyer D, Kaymak H, Klabe K, Lucchesi R, Teisch S, Gerl M, Kretz FTA (2018) Postoperative results in patients implanted with a novel enhanced depth of focus intraocular lens. EC Ophthalmol 9(4):192–202
16. Webers VSC, Bauer NJC, Saelens IEY, Creten OJM, Berendschot TTJM, van den Biggelaar FJHM, Nuijts RMMA (2020) 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 46(2):193–203
17. Singh B, Sharma S, Dadia S, Bharti N, Bharti S (2020) Comparative evaluation of visual outcomes after bilateral implantation of a diffractive trifocal intraocular lens and an extended depth of focus intraocular lens. Eye Contact Lens 46(5):314–318
18. Tarib I, Kasier I, Herbers C, Hagen P, Breyer D, Kaymak H, Klabe K, Lucchesi R, Teisch S, Diakonis VF, Hahn U, Fabian H, Kretz FTA (2019) Comparison of visual outcomes and patient satisfaction after bilateral implantation of an EDOF IOL and a mix-and-match approach. J Refract Surg 35(7):408–416
19. Ganesh S, Brar S, Pawar A (2017) Long-term visual outcomes and patient satisfaction following bilateral implantation of trifocal intraocular lenses. Clin Ophthalmol 11:1453–1459
20. Escandon-Garcia S, Ribeiro FJ, McAlinden C, Queirós A, González-Méijome JM (2018) Through-focus vision

performance and light disturbances of 3 new intraocular lenses for presbyopia correction. J Ophthalmol 2018:8
21. Law EM, Aggarwal RK, Kasaby H (2014) Clinical outcomes with a new trifocal intraocular lens. Eur J Ophthalmol 24:501–5088