Japanese Journal of Ophthalmology (2019) 63:429–436
https://doi.org/10.1007/s10384-019-00693-4

THE OFFICIAL INTERNATIONAL JOURNAL OF THE JAPANESE OPHTHALMOLOGICAL SOCIETY

CLINICAL INVESTIGATION

Comparison of visual outcomes between bilateral trifocal intraocular lenses and combined bifocal intraocular lenses with different near addition

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Received: 12 March 2019 / Accepted: 30 August 2019 / Published online: 22 October 2019

Abstract

Purpose To compare outcomes in patients implanted bilaterally with a trifocal intraocular lens (IOL) with patients implanted with bifocal IOLs having different near addition in each eye.

Study design Nonrandomized comparative study.

Methods Seventy-eight patients scheduled for multifocal IOL implantation were divided into a trifocal group (n=32) implanted bilaterally with trifocal IOLs (Alcon TFNT00), and a combined bifocal group (n=46) implanted with a bifocal IOL with +3.0 diopter (D) addition in the dominant eye and +4.0D addition in the nondominant eye. At 3 months postoperatively, binocular all-distance visual acuity (VA), binocular contrast VA alone and with glare (glare VA), near stereoacuity, and incidence of patients reporting halo symptoms were assessed.

Results Both mean binocular uncorrected and corrected VAs at far to intermediate distances were significantly better in the trifocal group than in the combined bifocal group ($P \leq 0.0325$), while binocular near VA did not differ significantly between groups. Mean photopic and mesopic contrast VA and glare VA at most contrasts, and stereoacuity were significantly better in the trifocal group than in the combined bifocal group ($P \leq 0.0426$). The incidence of patients reporting moderate halo symptoms was significantly greater in the trifocal group ($P=0.0482$).

Conclusions Bilateral implantation of a trifocal IOL provided significantly better binocular VA at far to intermediate distances and comparable near VA compared with combined implantation of bifocal IOLs with +3.0D and +4.0D addition. Contrast VA and stereoacuity were significantly better, but the incidence of halo symptoms tended to be worse in patients with trifocal IOLs.

Keywords Cataract surgery · Trifocal intraocular lens · Combined implantation of bifocal intraocular lenses · Near addition power · Binocular visual function

Introduction

Diffractive multifocal intraocular lenses (IOLs) were originally designed as bifocal IOLs with a +3.5 to +4.0 diopter (D) of near addition power to provide a reading distance of approximately 0.3 m [1–4]. In patients with implanted implanted bifocal IOLs with a +3.0 D to 4.0 D near addition power OU, however, visual acuities (VAs) at intermediate distances were not sufficient to perform intermediate distance tasks, including computer work [4–6]. Two methods are proposed to improve intermediate vision with multifocal IOLs without compromising near vision; (1) combined implantation of bifocal IOLs with high near addition power in one eye and low near addition power in the other eye [7, 8], and (2) bilateral implantation of trifocal IOLs [9–14].

Trifocal IOLs provide useful distance, intermediate, and near vision with a high rate of patient satisfaction and spectacle independence [9–12]. In addition, monocular intermediate VA is significantly better in eyes implanted with a trifocal than in eyes implanted with a bifocal IOL [15–17]. Furthermore, several studies reveal that bilateral implantation of trifocal IOLs provides better intermediate VA than combined implantation of bifocal IOLs with +3.0 D

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(AcrySof ReSTOR, SN6AD1; Alcon Laboratories) and +2.5 D near addition powers (SV25T0; Alcon) [18–20]. However, because reading distance differs according to body height the combined implantation of bifocal IOLs with +3.0 D and +4.0 D near addition power is suitable for people with a shorter stature, which includes many Asians [8]. Currently, there are no reports comparing visual function between those with bilateral implantation of trifocal IOLs and with combined implantation of bifocal IOLs with +3.0 D and +4.0 D near addition.

A new type of trifocal IOL (AcrySof PanOptix, TFNT00; Alcon) was recently developed. This IOL has a quadrifocal diffractive structure with three step-heights of addition power, and, therefore, the focal points are ∞, 1.2, 0.6, and 0.4 m [12]. Because the light from the first focal point (1.2 m) optimizes the distance vision, however, this IOL actually acts as a trifocal IOL. A recent study reveals that the PanOptix trifocal IOL can provide excellent distance VA in addition to intermediate VA without compromising distance contrast sensitivity [20].

The purpose of the present study was to compare binocular visual function between patients who underwent bilateral implantation of the new trifocal IOL (trifocal group) and patients who underwent combined implantation of a bifocal IOL with +3.0 D near addition in the dominant eye and +4.0 D near addition powers in the nondominant eye (combined bifocal group). We were particularly interested in whether the quadrifocal design improves distance VA and contrast sensitivity in addition to intermediate vision.

Subjects and methods

Study design

This study was a prospective nonrandomized comparative study. It was an exploratory study to compare binocular visual outcomes between patients who underwent bilateral implantation of a trifocal IOL and patients who underwent combined implantation of bifocal IOLs with +3.0 D near addition power in the dominant eye and +4.0 D near addition power in the nondominant eye. The patients were not randomized because only patients who participated in the PanOptix clinical trial could receive the trifocal IOL. The study was conducted at the Hayashi Eye Hospital in Fukuoka, Japan, between January 30, 2014 and January 18, 2017. This study adhered to the tenets of the Declaration of Helsinki. The Institutional Review Board of the Hayashi Eye Hospital approved the study design, and written informed consent was obtained from all patients. The study was registered in the University Hospital Medical Information Network (UMIN0000333175).

Participants

All patients who elected to undergo bilateral implantation of multifocal IOLs were screened by clinical research coordinators. The 32 patients in the trifocal group had expressed a wish to participate in the clinical trial of the PanOptix trifocal IOL. Preoperative exclusion criteria for both groups were patients with any pathology of the cornea, macula or optic nerve; opaque media other than cataract; history of ocular inflammation or surgery; corneal astigmatism of 1.0 D or more; marked irregular corneal astigmatism; amblyopia; patients who had participated in another clinical trial; and any difficulties with examinations, analyses, or follow-up. Intraoperative exclusion criteria were a small pupillary diameter that required pupil expansion procedures and eventful surgery. The physicians informed all patients who met the inclusion criteria of the possible advantages and disadvantages of bilateral implantation of trifocal or bifocal IOLs, or of combined implantation of bifocal IOLs with different near addition powers. After confirming the understanding of the explanation, both patients who were selected to undergo bilateral implantation of the trifocal IOLs and of combined implantation of bifocal IOLs were enrolled in the study.

Multifocal IOLs

The trifocal IOL (TFNT00) was implanted in patients of the trifocal group OU. The PanOptix is a single-piece aspheric hydrophobic acrylic IOL with optic diameter of 6.0 mm and an overall length of 13.0 mm. The diffractive structure is located within the central 4.5-mm optic zone, and comprises 15 concentric steps that divide the incoming light to create +1.08 D distance, +2.17 D intermediate, and +3.25 D near addition powers. This IOL utilizes the principle of quadrifocal technology, and, therefore, the focal points were ∞, 1.2, 0.6, and 0.4 m [12]. Because the light from the first focal point (1.2 m) is diffracted to the distance focal point (∞ m), the IOL acts as a trifocal IOL with distance, intermediate (0.6 m), and near focal points (0.4 m).

The patients in the combined bifocal group received a bifocal IOL with +3.0 D near addition power (SN6AD1) in the dominant eye, and a bifocal IOL with +4.0 D near addition power (SN6AD3) in the nondominant eye. Our previous study showed that distance contrast visual acuity was significantly better in eyes that received a bifocal IOL with +3.0 D addition than in eyes that received a bifocal IOL with +4.0 D addition [21]. To obtain better distance contrast sensitivity, we decided to implant a bifocal IOL with +3.0 D addition in the dominant eye [22]. The

dominant eye was determined using a hole-in-card test (sighting dominance) in which the patients were asked to look at a Landolt target at 5 m through a 1-cm hole in the center of the card board. The SN6AD1 and SN6AD3 have the same IOL platform as the PanOptix trifocal IOL. The diffractive structure is located within the central 3.6-mm zone, and comprises 9 or 12 concentric steps of decreasing height, thereby creating bifocality from distance to near. Target postoperative refraction in all patients in all patients was emmetropia.

Surgical techniques

All surgery was performed by a single surgeon (K.H.) using a previously described surgical procedure [23]. Cataract surgery on the second eye was performed approximately 2 days after the first. First, two side ports were made with a 0.6-mm slit knife at approximately 90° away from the main incision. A continuous curvilinear capsulorrhexis measuring approximately 5.0 mm in diameter was created using a bent needle. The surgeon then made a 2.4-mm single-plane clear corneal incision using a steel keratome horizontally for eyes having against-the-rule or oblique corneal astigmatism, and superiorly for eyes having with-the-rule astigmatism. After hydrodissection, phacoemulsification of the nucleus and aspiration of the residual cortex were conducted. The lens capsule was inflated with 1% sodium hyaluronate (Hyaguard, Nitten Co. Ltd), after which the IOL was placed into the capsular bag using a Monarch II injector with a D cartridge (Alcon). After IOL insertion, the ophthalmic viscoelastic material was thoroughly evacuated. In this series, all surgery was uneventful, and all IOLs were implanted in the capsular bag.

Outcome measures

At 3 months postoperatively, all patients underwent examinations of binocular uncorrected or corrected VA at far to near distances, binocular contrast VA with and without glare, near stereoacuity, refractive states, corneal astigmatism, and pupillary diameter. Corrected VA was measured using manifest subjective refraction with reference to the objective refraction. The primary endpoint was binocular uncorrected VA from far to near distances measured using an all-distance vision tester (AS-15; Kowa Co., Ltd). Binocular uncorrected and corrected VA at far to near distances was measured using the AS-15. The procedures used to measure VA at the various distances using the AS-15 were described previously [4, 8]. This device measures an equivalent VA at ∞, 5.0-, 3.0-, 2.0-, 1.0-, 0.7-, 0.5-, and 0.3-m distances by placing a spherical lens and variously-sized visual targets at appropriate distances along the visual axis. In the present study, we defined VA from 1.0 to 0.5 m as intermediate VA, and VA at 0.3 m as near VA.

After distance correction, binocular VA at high to low contrast levels (contrast VA) and in the presence of a glare source (glare VA) under photopic and mesopic conditions were examined using the Contrast Sensitivity Accurate Tester (CAT-2000; Menicon Co., Ltd) [21–23]. This device measures the logarithm of the minimal angle of resolution (logMAR) VA using five visual target contrasts. Measurement underphotopic condition was performed with a chart luminance of 100 candelas (cd)/m^2, while that under mesopic condition was performed with a chart luminance of 2 cd/m^2. A glare source of 200 lx was placed in the periphery at 20° around the visual axis.

Near stereoacuity with correction at 0.4 m was measured using the Titmus stereo test under photopic conditions (80–100 cd/m^2). Measurement was performed without correction for near vision. Near stereoacuity was determined by the number of circles answered correctly by the patients, and this number was converted to seconds of arc (arc sec) for statistical analysis. A stereoacuity of 100 arc sec was thought to be the lowest limit of useful stereoacuity [24].

The objective refractive status and keratometric astigmatism were measured using an autorefractometer (KR-7100; Topcon Co., Ltd). The manifest spherical equivalent value was determined as the spherical power plus half the cylindrical power. The pupillary diameter when looking at far visual targets was examined using the Alcon pupillometer (Cockrell Printing Company). The ocular higher-order aberrations (HOAs) were measured using a Hartmann-Shack wavefront aberrometer (KR-1W: Topcon). Ocular HOAs were measured in the central 6.0-mm optical zone.

Glare and halo symptoms were evaluated by administering a patients' questionnaire and also classified according to the patient's response; severe, moderate, slight, and none.

Statistical analysis

StatView 5.01 software (SAS) was used for statistical analysis. Monocular data obtained OU were averaged, and the mean value was used as a representative value for each patient. Decimal VA measured using the AS-15 was converted to the logMAR scale for statistical analyses. Normality of the data distribution was tested by inspection of histograms. Because the data of the logMAR VA, contrast VA and glare VA, near stereoacuity, and other continuous variables were normally distributed, an unpaired *t* test was used to compare the trifocal and combined bifocal groups. Categorical variables were compared using the chi-square test or Fisher's exact probability test where appropriate. Differences with a *P* value of less than 0.05 were considered significant.

Results

Thirty-two patients underwent bilateral implantation of the trifocal IOL (trifocal group), and 46 patients underwent combined implantation of bifocal IOLs with +3.0 D and +4.0 D near addition power (combined bifocal group). All patients completed the scheduled examinations at 3 months postoperatively. Preoperative demographic data of the patients are shown in Table 1. Mean patient age, ratio of men to women, preoperative refractive astigmatism, and preoperative corneal astigmatism did not differ significantly between the trifocal and combined bifocal groups ($P \geq 0.1618$; Table 1). Mean preoperative manifest spherical equivalent value and target refraction were significantly more myopic in the combined bifocal group than in the trifocal group ($P \leq 0.0090$). Demographic data at 3 months after surgery are shown in Table 2. Mean manifest spherical equivalent value, refractive astigmatism, pupillary diameter, and ocular total higher-order aberrations did not differ significantly between groups. Mean binocular uncorrected (UDVA) and corrected distance VA (CDVA) measured using ETDRS charts was significantly better in the trifocal group than in the combined bifocal group ($P < 0.0001$).

Binocular VA at far to near distances measured using the all-distance vision tester

Mean binocular UDVA, uncorrected intermediate VA (UIVA; Fig. 1), mean binocular CDVA and corrected intermediate VA (CIVA; Fig. 2) at far to intermediate distances (∞, 5.0, 3.0, 2.0, 1.0, 0.7, and 0.5 m) were significantly better in the trifocal group than in the combined bifocal group ($P \leq 0.0325$), and mean binocular uncorrected (UNVA) and corrected near VA (CNVA) at 0.3 m did not differ significantly between groups. The distribution of binocular UDVA at ∞ m and binocular UIVA at 1.0 m was significantly better in the trifocal group than in the combined bifocal group ($P \leq 0.0005$), and of UNVA at 0.3 m was not significantly different between groups

Table 1 Comparison of preoperative patient demographic data between patients who underwent bilateral implantation of trifocal intraocular lenses (trifocal group) and patients who underwent combined implantation with +3 D and +4 D near addition power (combined bifocal group)

	Trifocal Group	Combined Bifocal Group	*P*
Age (years)	67.1 ± 5.1	66.1 ± 6.1	0.3004
Sex (male/female)	10/22	18/28	0.1176
MRSE (D)	0.23 ± 1.44	-4.13 ± 13.1	0.0071*
Refractive astigmatism (D)	0.41 ± 0.63	0.32 ± 0.54	0.8805
Corneal astigmatism (D)	0.50 ± 0.27	0.67 ± 0.54	0.1618
Target refraction	0.01 ± 0.12	-0.15 ± 0.15	< 0.0001*

MRSE = Manifest spherical equivalent value; D = diopter

*Statistically significant difference between groups

Table 2 Comparison of patient data at 3 months postoperatively between those who underwent bilateral implantation of trifocal intraocular lenses (trifocal group) and those who underwent combined implantation with +3 D and +4 D near addition (combined bifocal group)

	Trifocal Group	Combined Bifocal Group	*P*
MRSE (D)	0.51 ± 0.34	0.69 ± 0.45	0.3535
Refractive astigmatism (D)	0.41 ± 0.63	0.32 ± 0.54	0.8805
Pupillary diameter (D)	3.40 ± 0.70	3.33 ± 0.53	0.4639
Ocular total HOAs (m)	0.18 ± 0.09	0.19 ± 0.13	0.4973
LogMAR UDVA	-0.04 ± 0.10	0.10 ± 0.13	< 0.0001*
LogMAR CDVA	-0.16 ± 0.07	-0.02 ± 0.06	< 0.0001*

MRSE = Manifest spherical equivalent value; D = dioptre; LogMAR = logarithm of the minimal angle of resolution; UDVA = uncorrected distance visual acuity; CDVA = corrected distance visual acuity

*Statistically significant difference between groups

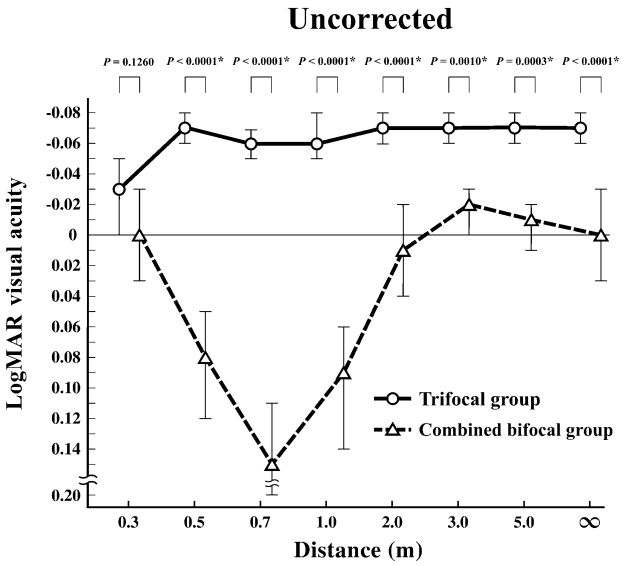

Fig. 1 Comparison of mean (± standard deviation) binocular uncorrected visual acuity (VA) at far to near distances expressed in logarithm of minimal angle of resolution (logMAR) scale between patients who underwent bilateral implantation of trifocal intraocular lenses (trifocal group) and patients who underwent combined implantation of bifocal IOLs with +3 D and +4 D near addition power (combined bifocal group) at 3 months postoperatively. *P value indicates a significant difference between the two groups

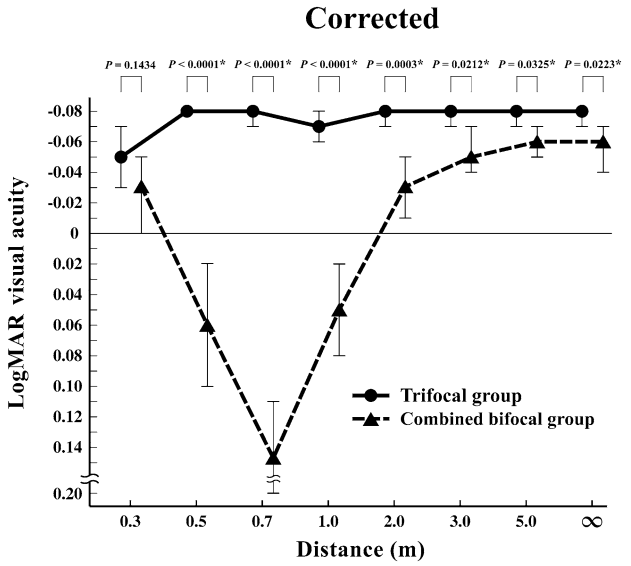

Fig. 2 Comparison of mean (±standard deviation) binocular corrected visual acuity (VA) at far to near distances expressed in logarithm of minimal angle of resolution (logMAR) scale between patients who underwent bilateral implantation of trifocal intraocular lenses (trifocal group) and patients who underwent combined implantation of bifocal IOLs with +3 D and +4 D near addition power (combined bifocal group) at 3 months postoperatively. *P value indicates a significant difference between the two groups

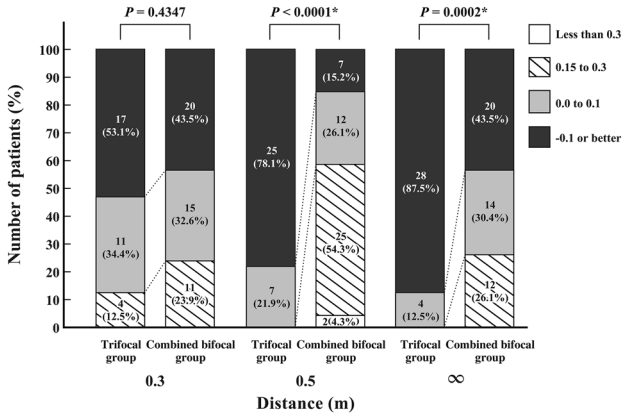

Fig. 3 Comparison of distribution of binocular uncorrected logarithm of minimal angle of resolution (logMAR) visual acuity at far, intermediate, and near distances between patients who underwent bilateral implantation of trifocal intraocular lenses (trifocal group) and patients who underwent combined implantation of bifocal IOLs with +3 D and +4 D near addition power (combined bifocal group) at 3 months postoperatively. *P value indicates a significant difference between the two groups

(Fig. 3). The distribution of binocular CDVA at ∞ m and CIVA at 1.0 m was significantly better in the trifocal group than in the combined bifocal group ($P \leq 0.0421$), and that of CNVA at 0.3 m was not significantly different between groups.

Binocular contrast VA and glare VA under photopic and mesopic conditions

Mean binocular contrast VA after distance correction under photopic and mesopic conditions was significantly better in the trifocal group than in the combined bifocal group ($P \leq 0.0426$), except for photopic contrast VA at 2.5% contrast of visual target and mesopic contrast VA at 10% contrast (Fig. 4). Mesopic binocular contrast VA at 5% and 2.5% contrast could not be statistically compared because they were below the detection limit in most eyes. Mean binocular glare VA under photopic or mesopic conditions was significantly better in the trifocal group than in the combined bifocal group ($P \leq 0.0345$), except for photopic and mesopic glare VAs at 100% contrast. Photopic glare VA at 2.5% contrast and mesopic glare VA at 5% and 2.5% contrast were under the detection limit in most eyes.

Near stereoacuity

The mean near stereoacuity was 53.1 ± 16.6 arc sec in the trifocal group and 110.7 ± 122.3 arc sec in the combined bifocal group; the mean value was significantly better in the trifocal than in the combined bifocal group ($P = 0.0101$). The number (%) of patients who achieved a disparity threshold of 100 arc sec or less was 31 (96.9%) in the trifocal, and 32 (69.6%) in the combined bifocal group; the percentage was significantly higher in the trifocal than in the combined bifocal group ($P = 0.0027$).

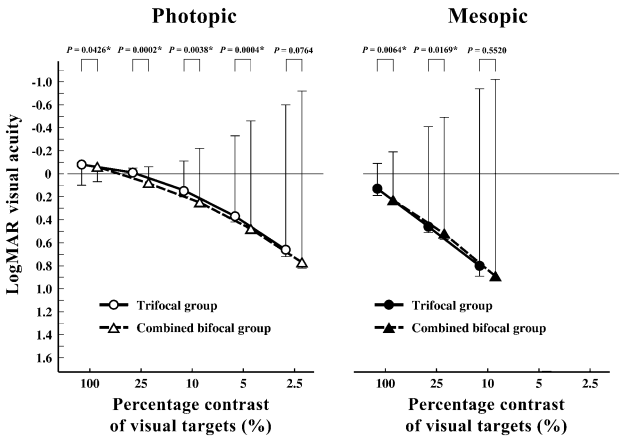

Fig. 4 Comparison of mean (±standard deviation) binocular photopic and mesopic contrast visual acuity (contrast VA) expressed in logarithm of minimal angle of resolution (logMAR) scale between patients who underwent bilateral implantation of trifocal intraocular lenses (trifocal group) and patients who underwent combined implantation of bifocal IOLs with +3 D and +4 D near addition power (combined bifocal group) at 3 months postoperatively. *P value indicates a significant difference between the two groups

Halo and glare symptoms

The number (%) of patients who reported halo symptoms was 21 (65.6%) in the trifocal, and 37 (80.4%) in the combined bifocal group; the percentage was significantly lower in the trifocal than in the combined bifocal group ($P = 0.0162$; Table 3). The number (%) of patients who reported moderate halo symptoms, however, was 11 (34.4%) in the trifocal group and 7 (15.2%) in the combined bifocal group; the percentage of patients who reported moderate halo symptoms was significantly greater in the trifocal group than in the combined bifocal group ($P = 0.0482$; Table 3). The number (percentage) of patients who reported glare symptoms was 14 (43.8%)in the trifocal group and 23 (50.0%)in the combined bifocal group; the percentage of patients did not differ significantly between groups ($P = 0.5570$; Table 3).

Discussion

The findings of the present study reveal that binocular mean uncorrected and corrected VAs from far to intermediate distances were significantly better and near VA was comparable in patients who underwent bilateral implantation of the trifocal compared with patients that underwent combined implantation of a bifocal IOL with +3.0 D in the dominant eye and +4.0 D near addition power in the nondominant eye. Additionally, the distribution of UDVA at ∞ m and UIVA at 1.0 m was significantly better in the patients who received the trifocal IOL in both eyes than in patients who received a bifocal IOL with a different addition power in each eye, while that of UNVA at 0.3 m was comparable between the groups. These findings suggest that the trifocal IOL provides a broad range of significantly better VA than combined implantation of bifocal IOLs with +3.0 D and +4.0 D near addition, although near VA was similar between groups.

Binocular contrast VA with and without glare was significantly better at most contrasts in patients who received the trifocal IOL OU than in patients who received bifocal IOLs with different addition power in each eye. When comparing patients with the trifocal IOL in the present study and patients with a monofocal IOL examined in our previous studies [8, 25], binocular contrast VA and glare VA were comparable. Additionally, the near stereoacuity was significantly better in the trifocal group than in the combined bifocal group. The percentage of patients who achieved useful stereoacuity was 96.9% in the trifocal group and 69.6% in the combined bifocal group; the percentage was also significantly higher in the trifocal group than in the combined bifocal group. The results of near stereoacuity in the combined bifocal group were comparable to those in a previous study [22]. These findings suggest that binocular visual function is not markedly impaired in patients with trifocal IOLs.

The incidence of patients who reported overall halo symptoms was significantly lower in the trifocal group than in the combined bifocal group, while the incidence of patients who reported glare symptoms was similar between groups. The percentage of patients who reported moderate halo symptoms, however, was 34.4% in the trifocal and 15.2% in the combined bifocal group; the incidence was significantly greater in the trifocal than in the combined bifocal group. Thus, clinically significant halo symptoms were more common in patients with trifocal IOLs than in patients with bifocal IOLs. This is probably because the trifocal IOL causes more extensive halo symptoms than the bifocal IOLs.

Bifocal IOLs have a critical disadvantage of worse intermediate VA, because the focal points are only far and near. To obtain excellent intermediate to near VA, combined implantation of different near addition power in each eye is currently performed, and is thought to be the best available option to achieve useful intermediate and near vision [7, 8]. Trifocal IOLs, however, have three focal points at far, intermediate, and near distances, and, therefore, provide better monocular intermediate VA than do bifocal IOLs [15–17]. Furthermore, several studies report that bilateral implantation of trifocal IOLs provides better intermediate VA than the combined implantation of bifocal IOLs of +3.0 D and +2.5 D near addition [18–20]. Specifically, Vilar et al. [20] reveal that bilateral implantation of the new trifocal IOL with quadrifocal technology provides significantly better intermediate VA and contrast sensitivity than combined implantation of bifocal IOLs with +3.0 D and +2.5 D addition. The findings of the present study also demonstrate that, in patients with bilateral trifocal IOLs, intermediate VA was significantly better and near VA was similar compared with patients implanted with bifocal IOLs having +4.0 D and +3.0 D addition. Considering these findings together,

Table 3 Number (%) of patients who reported halo or glare symptoms

	Trifocal Group	Combined Bifocal Group	*P*
Halo symptom			0.0162*
Severe	5 (15.6%)	8 (17.4%)	
Moderate	11 (34.4%)	7 (15.2%)	
Slight	5 (15.6%)	22 (47.8%)	
None	11 (34.4%)	9 (19.6%)	
Glare symptom			0.5570
Severe	2 (6.3%)	6 (13.0%)	
Moderate	5 (15.6%)	4 (8.7%)	
Slight	7 (21.9%)	13 (28.3%)	
None	18 (56.3%)	23 (50.0%)	

*Statistically significant difference between groups using the goodness test of fit for chi-square

intermediate VA in patients with combined implantation of bifocal IOLs with different near addition is inferior to that in patients with bilateral trifocal IOLs.

Because reading distance differs according to body height, however, combined implantation of bifocal IOLs with +3.0 D and +4.0 D near addition is more suitable for shorter people, which includes many Asians [8]. Accordingly, we compared the binocular visual outcomes between patients who underwent bilateral implantation of the new trifocal IOL and patients who underwent combined implantation of bifocal IOLs with +3.0 D and +4.0 D near addition. Our findings revealed that binocular visual function, in terms of distance VA, contrast sensitivity, and stereopsis, was superior in patients implanted with bilateral trifocal IOLs compared with patients implanted with bifocal IOLs having a different near addition power. Furthermore, intermediate VA was significantly better in patients with bilateral trifocal IOL, but near VA was comparable between patients with trifocal IOLs and patients with bifocal IOLs with +4.0 D and +3.0 D near addition.

In the present study, the new trifocal IOL provided excellent VA from far to intermediate distances and good distance contrast VA with and without glare, comparable to monofocal IOLs. This IOL has a large diffractive region comprising 15 steps that divide the incoming light to create +1.08 D far to intermediate (1.2 m), +2.17 D intermediate (0.6 m), and +3.25 D near addition (0.4 m) powers. Because this IOL utilizes quadrifocal technology, however, the light from the first focal point (1.2 m) diffracts the light energy to the distance focal point, reducing the overall loss of light energy [12]. Thus, the increased light energy to the far to intermediate distances with this trifocal IOL might provide a broad range of excellent VA and improved contrast sensitivity with and without glare.

The present study may be limited by the fact it was a non-randomized study. Only patients who wished to receive the trifocal IOL could participate in the clinical trial, and, therefore, the eligible patients could not be randomized.

In conclusion, bilateral implantation of a new trifocal IOL with quadrifocal technology provided significantly better binocular far to intermediate VA and comparable near VA compared with combined implantation of bifocal IOLs with +3.0 D and +4.0 D near addition. Contrast sensitivity with and without glare and near stereoacuity were significantly better in patients with the trifocal IOL OU than in patients with the bifocal IOLs with different addition power. The incidence of patients who reported clinically significant halo symptoms, however, was greater in the trifocal group than in the combined bifocal group. Using bifocal IOLs, combined implantation is thought to be the best currently available option to achieve useful intermediate vision. Based on the findings of the present study, however, we consider bilateral implantation of the trifocal IOL superior to combined implantation of bifocal IOLs. Recently, some surgeons reported a preference for extended depth of focus IOLs [26, 27]. Further study is necessary to compare binocular visual function between the trifocal IOL and extended depth of vision IOL, particularly utilizing the monovision method.

Acknowledgements The authors thank Koji Yonemoto, PhD (Ryukyu University, Naha, Japan) for statistical assistance.

Financial support None.

Conflicts of interest K. Hayashi, None; T. Sato, None; C. Igarashi, None; M. Yoshida, None.

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