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Implantation of diffractive extended depth-of-focus intraocular lenses in normal tension glaucoma eyes: A case series

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ABSTRACT

Purpose: Implantation of presbyopia-correcting intraocular lenses (IOLs) has not been advised for glaucomatous eyes because of the risk of decreased contrast sensitivity with progress of glaucoma. Extended depth-of-focus (EDF) IOLs have been reported to provide comparable postoperative visual function and influence on the visual field to monofocal IOLs.

Methods: This case series was a retrospective medical record review of 16 eyes of 10 patients who had normal tension glaucoma (NTG) with no central visual field defects and underwent cataract surgery with implantation of diffractive EDF IOLs. At 3 months postoperatively, distance-corrected visual acuities (DCVAs) at distances of 5, 1, and 0.5 m and photopic contrast sensitivity were examined. Automated perimetry using the 30-2 Swedish interactive threshold algorithm was also performed, and the mean variance (MD) values, mean deviation values at the central four points (central MD), and foveal threshold were recorded.

Results: The mean age of the patients (5 men, 5 women) was 66.5 years. Over 80% of eyes obtained DCVAs of 20/20, 20/20, and 20/25 at 5 m, 1 m, and 0.5 m, respectively. Whereas 5 of 16 eyes were categorized as severe by the Hodapp-Parrish-Anderson classification, postoperative contrast sensitivity was within the normal range, except for 4 eyes at 18 cycles per degree.

Conclusions and importance: In this case series, the postoperative visual functions of NTG patients with EDF IOLs were almost comparable to those of normal eyes with the same IOLs, which demonstrated that the use of EDF IOLs for controlled NTG eyes would be permissible. While careful patient selection and follow-up for NTG progress are important, further investigations are necessary for confirming the safety and exploring the selection criteria.

1. Introduction

Presbyopia-correcting intraocular lenses (IOLs) have been implanted to provide spectacle independence or less spectacle dependence after cataract surgery. Due to photic phenomena and decreased contrast sensitivity, implantation of these IOLs has been restricted to eyes without ocular comorbidities.[1,2] Glaucomatous eyes are at a risk of decreased contrast sensitivity depending on their status, so that the visual function after implantation of bifocal IOL has been discussed.[1,3,4] Although some studies of presbyopia-correcting IOLs have included glaucomatous eyes, the numbers of these eyes were limited or the implanted IOLs were refractive bifocal models.[5,6]

IOLs with lower near additional powers have been developed to minimize contrast sensitivity reductions; a diffractive extended depth-of-focus (EDF) IOL with an echelette grating provides comparable postoperative contrast sensitivity to monofocal IOLs.[7] Evaluations of automated perimetry in non-glaucomatous eyes with diffractive EDF IOLs have identified effects similar to those with monofocal IOLs.[8,9] With these findings, the degradation of visual function with EDF IOLs may be permissible for cases with glaucoma.

Primary open angle glaucoma (POAG) accounts for most cases of glaucoma. In the assessment in 2013, approximately 23.54 million individuals were estimated to have POAG in Asia.[10] In Japan, normal tension glaucoma (NTG) is the most common type.[11] Thus, it is speculated that a certain number of undiagnosed NTG cases are included among cataract patients. In a nationwide cohort study in Japan, 52 of 1384 eyes implanted with a multifocal IOL had glaucoma preoperatively.[12] In our hospital, EDF IOLs were conservatively implanted in

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Table 1
Demographics of 16 primary open-angle glaucoma eyes of 10 patients receiving extended depth-of-focus intraocular lenses.

	Mean	Standard deviation, range
Age, years	66.5	7.1, 56–80
Axial length, mm	25.9	2.0, 22.9–28.8
Preoperative IOP, mmHg	12.0	2.5, 6.0–16.0
IOL power, D	14.9	5.9, 6.0–23.0

IOP: intraocular pressure, D: diopter.

Table 2
Postoperative manifest refraction spherical equivalent (MRSE) and distance-corrected visual acuities (DCVAs).

Case	Age (years)	MRSE (D)	DCVA, logMAR		
			at 5 m	at 1 m	at 0.5 m
1	65	−0.38	−0.18	−0.18	0.00
		−0.38	−0.18	−0.08	−0.08
2	65	−0.38	−0.18	0.00	0.10
		−0.38	−0.18	−0.08	0.00
3	67	0.25	−0.18	−0.08	0.10
		−0.25	−0.08	0.05	0.15
4	76	−0.50	−0.18	0.15	0.22
5	80	−0.25	−0.08	0.00	0.05
		−0.25	−0.08	0.00	0.10
6	56	−0.25	−0.18	0.00	0.22
7	65	0.00	−0.18	−0.08	0.10
8	62	−0.50	−0.18	−0.18	0.00
		−0.25	−0.18	0.00	−0.08
9	69	0.88	−0.08	0.00	0.05
10	60	−0.13	−0.18	−0.18	−0.08
		−0.50	−0.18	−0.18	0.05

logMAR: logarithm of the minimum angle of resolution, m: meter, intraocular pressure.

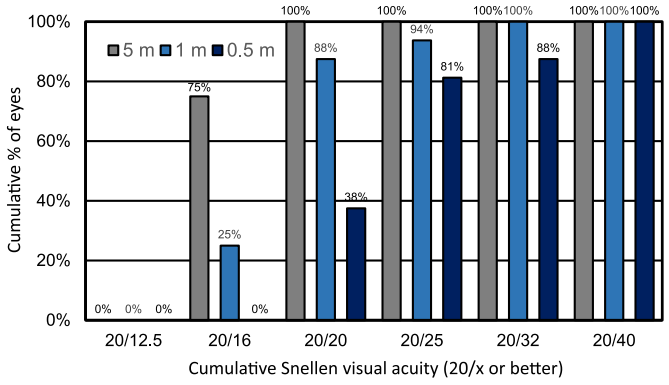

Fig. 1. Histogram of cumulative distance corrected visual acuities (DCVAs) at distances of 5, 1, and 0.5 m (m).

patients who had interest in presbyopia-correcting IOLs, when glaucoma was in the early stage, the intraocular pressure (IOP) and visual fields were controlled, and the central visual field was preserved. In our knowledge, clinical outcomes of implantation of EDF IOLs in NTG eyes has not been reported. Therefore, the clinical outcomes of NTG eyes that received EDF IOLs were reviewed.

2. Methods

Since December 2017, 16 NTG eyes of 10 patients (5 men, 5 women) received diffractive EDF IOLs (Symfony®, models ZXR00V and ZXV150-375, Johnson & Johnson Surgical Vision, Santa Ana, CA, USA) following cataract removal, and the medical records of these patients were reviewed. Written informed consent to use their data was obtained from

Table 3
Postoperative automated perimetry results and Hodapp-Parrish-Anderson (HPA) stages.

Case	Automated perimetry results (dB)			HPA stage
	MD	Central MD	Foveal threshold	
1	−5.14	−0.11	35	Moderate
	−6.45	−4.52	32	Severe
2	−3.08	−5.52	31	Moderate
	−4.84	−0.28	34	Moderate
3	−7.99	−0.60	35	Severe
	−4.89	−0.55	33	Moderate
4	−0.99	1.00	35	Early
5	−2.77	0.48	31	Early
	−8.67	−1.56	31	Severe
6	−5.65	−2.30	33	Severe
7	−2.94	−0.59	32	Moderate
8	−4.62	−0.30	36	Moderate
	−12.25	−2.30	33	Severe
9	−0.79	0.00	37	Early
10	−2.70	−0.12	36	Early
	−2.69	−1.00	34	Early

MD: mean variance, central MD: mean deviation values at the central four points.

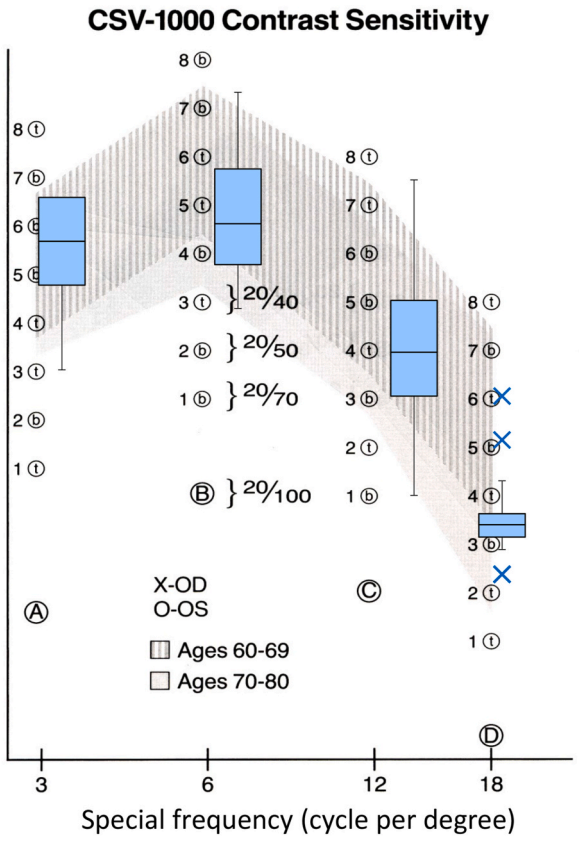

Fig. 2. Box plot of postoperative photopic contrast sensitivity at spacial frequencies of 3, 6, 12, and 18 cycle per degree. Gray areas present norm of normal persons with ages of 60–69 and 70–80 years. X in blue depicts outer value. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

all patients. This study was approved by the ethics committee of Tokyo Dental College. All procedures were in accordance with the tenets of the Declaration of Helsinki.

NTG was diagnosed in the same manner as in previous population studies.[11] The inclusion criteria for implantation were an age of 20 years and older, NTG controlled with minimal medical treatments (maximal

Table 4
Severities of glare, halos, and star bursts.

Case	Eye	Severity (none, mild, modest, severe)		
		Glare	Halos	Starbursts
1	Both	None	None	None
2	Both	Mild	None	Modest
3	Both	Mild	Mild	Mild
4	R	None	Severe	None
5	Both	None	None	None
6	L	Mild	None	None
7	L	None	None	None
8	Both	Mild	Modest	Mild
9	L	Modest	Modest	Modest
10	R	Mild	None	Severe

use of two eye drops), and no central loss of visual field sensitivity. Automated perimetry was performed using a Humphrey Field Analyzer III (Carl Zeiss Meditec AG, Jena Germany) with the 30-2 Swedish Interactive Threshold Algorithm (SITA) standard or fast programs. To ensure reliability, the rates of fixation loss, false-positive errors, and false-negative errors were confirmed as over 20%, 15%, and 33%, respectively. Indices of the mean variance (MD) values, mean deviation values at the central four points (central MD), and foveal threshold were recorded.

The implanted EDF IOLs were one-piece hydrophobic IOLs (length of 13 mm, optic diameter of 6 mm, 360-degree sharp edged) with anteriorly shifted haptics. The EDF function was produced using an echelette diffractive grating with add power of 1.75 diopter (D). Using biometry data such as axial length (AL), measured with the IOLMaster 700 (Carl Zeiss Meditec AG), powers of IOLs were determined based on the patient preference of postoperative refraction between emmetropia and myopia of −0.5 D. For eyes with corneal astigmatism of 0.75 D or more, toric versions were used. All patients underwent femtosecond laser-assisted cataract surgeries using the LenSx Laser System (version 2.23) and Centurion Vision System (Alcon Laboratories Inc., Fort Worth, TX, USA). IOLs were inserted into the capsule using an injector system through a temporal corneal incision of a width of 2.2 or 2.4 mm.

At 3 months postoperatively, distance-corrected visual acuities (DCVAs) were measured at distances of 5.0 m (far), 1.0 m (intermediate), and 0.5 m (near). Manifest refraction spherical equivalent (MRSE) was obtained during measurement at 5 m. Visual acuity values were converted to the logarithm of the minimum angle of resolution (logMAR). Contrast sensitivities at spatial frequencies of 3, 6, 12, and 18 cycle per degree (cpd) were measured using the CSV-1000 (Vector Vision, Fairfield, CT, USA) under photopic illumination (85 cd/m^2). Automated perimetry was also performed in the same manner as preoperatively. Regarding with photic phenomena, the severities of glare, halos, and star bursts were graded in 0.4 levels: none, mild, moderate, and severe.

3. Results

A summary of the patient demographics is shown in Table 1. There were no intraoperative and postoperative complications affecting postoperative visual function. There were 9 eyes with AL over 26.0 mm.

Postoperative MRSE and DCVAs of each eye are shown in Table 2. The mean DCVAs at the distances of 5, 1, and 0.5 m were −0.15, −0.05, and 0.06 logMAR, respectively. Fig. 1 shows a histogram of cumulative distance corrected visual acuities[13] at distances of 5, 1, and 0.5 m. Over 80% of eyes obtained distance corrected visual acuity of 20/20, 20/20, and 20/25 at the distances of 5 m, 1 m, and 0.5 m, respectively.

Table 3 lists the postoperative conditions of the NTG eyes, consisting of automated perimetry outcomes and the Hodapp-Parrish-Anderson (HPA) classification.[14] The mean MD, central MD, and foveal threshold were −4.78 dB, −1.14 dB, and 33.6 dB, respectively. Five eyes

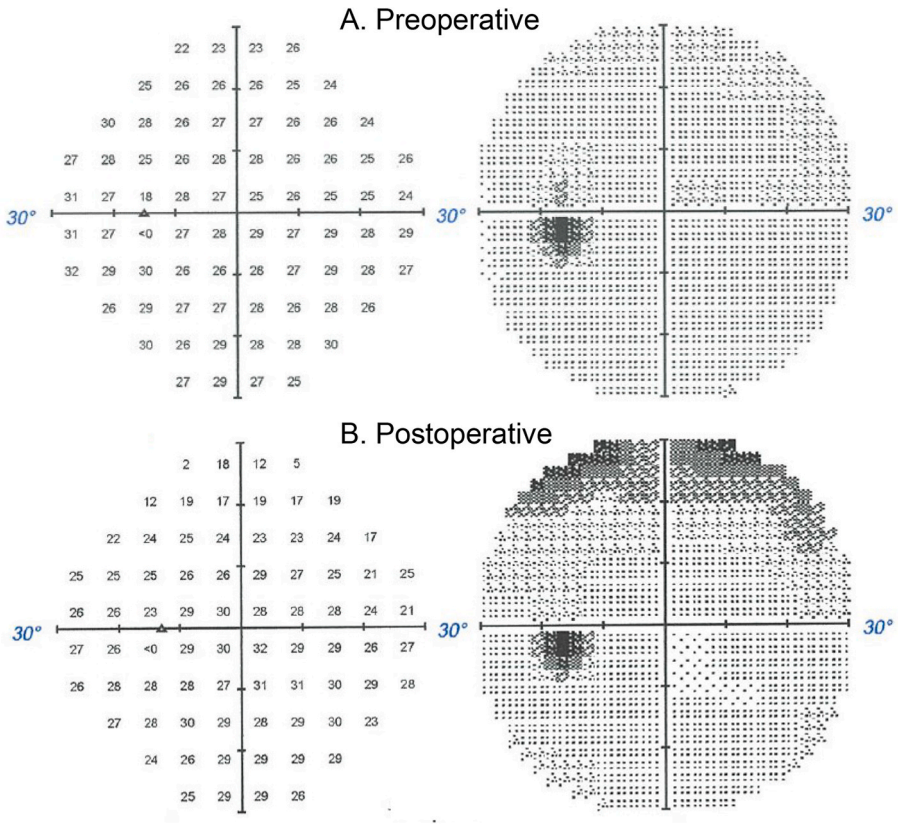

Fig. 3. Preoperative (top) and postoperative (bottom) visual field value (left) and grayscale (right) plots with 30-2 Swedish Interactive Threshold Algorithm (SITA) fast algorithm of the left eye of Case 7.

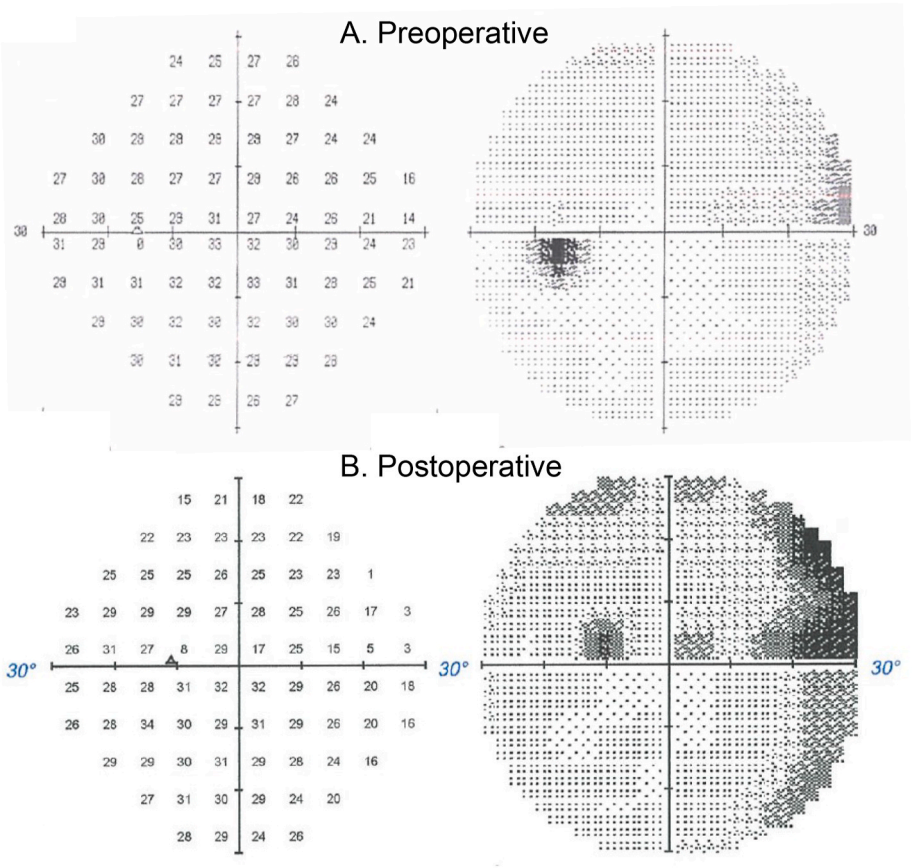

Fig. 4. Preoperative (top) and postoperative (bottom) visual field value (left) and grayscale (right) plots with 30-2 Swedish Interactive Threshold Algorithm (SITA) standard algorithm of the left eye of Case 8.

were categorized as severe in the HPA classification.

Fig. 2 shows a box plot of contrast sensitivity. In case 7, contrast sensitivities at 3 cpd and 12 cpd were lower than the norm levels (1.49 and 1.25 in logarithm contrast sensitivity, respectively). At 18 cpd, 4 eyes (left eye of case 2, both eyes of case5, and case9) were lower than the norm range (0.81 logarithm contrast sensitivity).

Table 4 lists the severities of glare, halos, and starbursts reported from patients. Most cases reported as none, mild, or moderate. Only one case of severe halos (Case 4) and one case of severe starbursts (Case 10) were reported.

Details of 2 cases of relatively mild and moderate severities of NTGs are described below:

Case 7

A 65-year-old Japanese man underwent cataract surgery of his left eye with EDF IOL implantation. The preoperative AL and IOP were 26.31 mm and 16.0 mmHg (non-contact), respectively. In the preoperative perimetry examination, MD, pattern standard deviation (PSD), and foveal threshold were −1.77 dB, 2.33 dB, and 30 dB, respectively, and there was no central defect in the visual field (top of Fig. 3). HPA stage was diagnosed as moderate, and an EDF IOL of 13.0 D was implanted, targeting a postoperative refraction of −0.5 D. Postoperative MD, PSD, and foveal threshold were −2.94 dB, 3.13 dB, and 32 dB, respectively. Bottom of Fig. 3 shows the postoperative perimetry pattern; there was no central defect. The superior defect was not reproducible in subsequent examinations and is inferred to be an upper eyelid effect. While visual acuities were good, contrast sensitivities at 3 and 12 cpd were below the norm.

Case 8 left eye

A 62-year-old Japanese man underwent bilateral cataract surgeries with EDF IOL implantations. The preoperative AL and IOP were 27.08 mm and 9.5 mmHg (non-contact), respectively. On preoperative perimetry, MD, PSD, and foveal threshold were −1.54 dB, 3.04 dB, and 36 dB, respectively, and there was no central defect in the visual field (top of Fig. 4). HPA severity was categorized as moderate. Although the possible risks were sufficiently explained, the patient desired the implantation of EDF IOLs. An EDF IOL of 12.0 D was implanted targeting emmetropia. Postoperative MD, PSD, and foveal threshold values were −4.62 dB, 7.05 dB, and 36 dB, respectively. In the postoperative perimetry pattern shown in the bottom of Fig. 4, there was no central defect and the sensitivity was slightly lower in a quadrant. There was no degradation in the postoperative visual acuity, and contrast sensitivity values were above the lower limits of norm at all spatial frequencies. While symptoms of mild glare and starburst, and modest halos were reported, the patient was satisfied with the postoperative outcomes.

4. Discussion

In the present case series of NTG eyes with diffractive EDF IOLs, there were no significant degradations in the distance corrected visual acuities. These results would be obtained by the selection criteria of controlled NTG with no central loss of visual field sensitivity.

As for contrast sensitivity, 4 of 16 eyes showed lower contrast compared at 18 cpd. The decrease of contrast sensitivities at higher spatial frequencies in eyes with presbyopia-correcting IOLs is well known.[2] However, a recent study demonstrated that the contrast sensitivity of eyes with EDF IOLs was comparable to that with monofocal IOLs.[7] An optical bench test indicated that the image contrast on the retina with diffractive EDF IOLs for far vision was comparable to the image with monofocal IOLs.[15] Both clinical and experimental findings

showed that the contrast sensitivity and the image contrast of EDF IOLs were comparable to those with monofocal IOLs. Thus, it was unclear whether EDF IOL or NTG was the factor responsible for the lower results at 18 cpd in the present case series. A glaucoma patient is at risk for reduction of mesopic contrast sensitivity.[16] A meta analysis[17] demonstrated that the contrast sensitivity of eyes with EDF IOLs would decrease under scotopic condition, compared with eyes with monofocal IOLs. Although measuring the contrast sensitivity under mesopic condition is not routinely performed, this examination would be beneficial to investigate the possible influence of compounding glaucoma and EDF IOL on patient's visual function.

Another concern of glaucomatous patients is the progress of symptoms, which may decrease MD values and contrast sensitivity.[18,19] Komori et al. addressed that the MD values decreased in 53.8% of NTG patients during a follow-up of 15 years or longer.[20] Although the clinical comparison of the MD values of normal eyes with EDF IOLs showed no difference from eyes with monofocal IOLs,[8] the influence on glaucomatous eyes over the longer term should be investigated. In addition, an analysis within 10° such as the 10-2 SITA testing is preferred to examine the details of the central visual field.[8,21] The incidence of NTG is high in Japan[10,11,22] and screening for glaucoma should be performed preoperatively.

Spectacle independence with the use of presbyopia-correcting IOLs is beneficial for glaucomatous patients, as well as normal patients. From the present findings, it could be anticipated that the use of EDF IOLs had less influence on patient visual function and would be tolerable for controlled NTG eyes. A prospective study with a larger number of cases should be conducted to evaluate the impact of EDF IOL implantation on NTG over the longer term and investigate the permissible severity for which the benefit of EDF IOL would outweigh the inferior visual function caused by NTG.

5. Conclusions

This was a report of a case series of implantation of EDF IOLs in 16 controlled-NTG eyes with no central defect. The postoperative visual functions were almost comparable to those of normal eyes after implantation of the same IOLs, up to 3 months postoperatively. While careful patient selection and further follow-up are important, the current cases demonstrated that the use of EDF IOLs is permissible.

Patient consent

Consent to publish the case report was not obtained. This report does not contain any personal information that could lead to the identification of the patients.

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Authorship

All authors attest that they meet the current ICMJE criteria for Authorship.

Declaration of competing interest

Hiroko Bissen-Miyajima, Yuka Ota, Manabu Hirasawa, Kenya Yuki, and Keiichiro Minami declare that they have no conflict of interest.

References

1. Braga-Mele R, Chang D, Dewey S, et al. Multifocal intraocular lenses: relative indications and contraindications for implantation. *J Cataract Refract Surg.* 2014;40:313–322.
2. Schallhorn JM, Pantanelli SM, Lin CC, et al. Multifocal and accommodating intraocular lenses for the treatment of presbyopia: a report by the American academy of ophthalmology. *Ophthalmology.* 2021;128:1469–1482.
3. Teichman JC, Ahmed II. Intraocular lens choices for patients with glaucoma. *Curr Opin Ophthalmol.* 2010;21:135–143.
4. Ichhpujani P, Bhartiya S, Sharma A. Premium IOLs in glaucoma. *J Curr Glaucoma Pract.* 2013;7:54–57.
5. Ouchi M, Kinoshita S. Implantation of refractive multifocal intraocular lens with a surface-embedded near section for cataract eyes complicated with a coexisting ocular pathology. *Eye (Lond).* 2015;29:649–655.
6. Kamath GG, Prasad S, Danson A, Phillips RP. Visual outcome with the array multifocal intraocular lens in patients with concurrent eye disease. *J Cataract Refract Surg.* 2000;26:576–581.
7. Pedrotti E, Bruni E, Bonacci E, Badalamenti R, Mastropasqua R, Marchini G. Comparative analysis of the clinical outcomes with a monofocal and an extended range of vision intraocular lens. *J Refract Surg.* 2016;32:436–442.
8. Lee J, Mori Y, Nejima R, Minami K, Miyata K. Influence of implantations of extended depth-of-focus on standard automated perimetry. *Sci Rep.* 2020;10, 20153.
9. Takahashi M, Yamashiro C, Yoshimoto T, et al. Influence of extended depth of focus intraocular lenses on visual field sensitivity. *PLoS One.* 2020;15, e0237728.
10. Tham YC, Li X, Wong TY, et al. Global prevalence of glaucoma and projections of glaucoma burden through 2040: a systematic review and meta-analysis. *Ophthalmol.* 2014;121:2081–2090.
11. Iwase A, Suzuki Y, Araie M, et al. The prevalence of primary open-angle glaucoma in Japanese: the Tajimi Study. *Ophthalmology.* 2004;111:1641–1648.
12. Negishi K, Hayashi K, Kamiya K, et al. Nationwide prospective cohort study on cataract surgery with multifocal intraocular lens implantation in Japan. *Am J Ophthalmol.* 2019;208:133–144.
13. Reinstein DZ, Archer TJ, Srinivasan S, et al. Standard for reporting refractive outcomes of intraocular lens-based refractive surgery. *J Refract Surg.* 2017;33:218–222.
14. Hodapp E, Parrish RK, Anderson DR. *Clinical Decisions in Glaucoma.* St Louis, MO: Mosby Inc.; 1993.
15. Lee S, Choi M, Xu Z, et al. Optical bench performance of a novel trifocal intraocular lens compared with a multifocal intraocular lens. *Clin Ophthalmol.* 2016;10:1031–1038.
16. Lahav K, Levkovitch-Verbin H, Belkin M, Glovinsky Y, Polat U. Reduced mesopic and photopic foveal contrast sensitivity in glaucoma. *Arch Ophthalmol.* 2011;129:16–22.
17. Liu J, Dong Y, Wang Y. Efficacy and safety of extended depth of focus intraocular lenses in cataract surgery: a systematic review and meta-analysis. *BMC Ophthalmol.* 2019;19:198.
18. Hawkins AS, Szlyk JP, Ardickas Z, Alexander KR, Wilensky JT. Comparison of contrast sensitivity, visual acuity, and Humphrey visual field testing in patients with glaucoma. *J Glaucoma.* 2003;12:134–138.
19. Fatehi N, Nowroozizadeh S, Henry S, et al. Association of structural and functional measures with contrast sensitivity in glaucoma. *Am J Ophthalmol.* 2017;178:129–139.
20. Komori S, Ishida K, Yamamoto T. Results of long-term monitoring of normal-tension glaucoma patients receiving medical therapy: results of an 18-year follow-up. *Graefes Arch Clin Exp Ophthalmol.* 2014;252:1963–1970.
21. Farid M, Chak G, Garg S, Steinert RF. Reduction in mean deviation values in automated perimetry in eyes with multifocal compared to monofocal intraocular lens implants. *Am J Ophthalmol.* 2014;158:227–231.
22. Kim KE, Park KH. Update on the prevalence, etiology, diagnosis, and monitoring of normal-tension glaucoma. *Asia Pac J Ophthalmol (Phila).* 2016;5:23–31.