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Comparative Evaluation of Visual Outcomes in Combined Cataract and Vitrectomy for Idiopathic Epiretinal Membrane with an Advanced or Conventional Intraocular Lens

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Keywords
Epiretinal membrane · Eyhance IOL · Combined cataract and vitrectomy surgery · Intermediate vision · Metamorphopsia

Abstract
Introduction: The aim of this study was to investigate the efficacy of new monofocal intraocular lens (IOL) in comparison with conventional monofocal IOL in patients undergoing combined cataract and vitrectomy surgery for epiretinal membrane (ERM). ***Methods:*** This prospective non-randomized comparative study included 65 eyes of 65 patients who underwent combined cataract and vitrectomy for ERM with implantation of advanced monofocal IOL (Eyhance ICB00, 33 patients) and standard monofocal IOL (Tecnis ZCB00, 32 patients). Monocular visual acuities were measured 6 months post-operatively, including corrected and uncorrected distance visual acuity (CDVA, UCDVA), uncorrected intermediate visual acuity (UCIVA), and uncorrected near visual acuity (UCNVA). Furthermore, contrast sensitivity and metamorphopsia were measured. ***Results:*** There was no significant difference between two groups regarding operation time, post-operative CDVA, UCDVA, UCNVA, and spherical equivalent ($p > 0.05$). Monocular UCIVA was significantly higher in the Eyhance IOL group than in the Tecnis IOL group ($p = 0.005$). The photopic and mesopic contrast sensitivities were comparable between each group for any spatial frequency ($p > 0.05$). The correlation coefficients from correlations between retinal wrinkling ratio and M score did not differ significantly between groups ($p = 0.877$), and the degree of metamorphopsia was not significantly related to the type of IOL ($p = 0.969$). ***Conclusions:*** In combined cataract and vitrectomy for ERM, Eyhance IOL provided significant better visual performance at intermediate distance than standard monofocal IOL without compromising operation time, distance vision, contrast sensitivity, and evaluating metamorphopsia. Eyhance IOL can be a useful option for both surgeons and patients.

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Introduction

Cataract formation is a major concern, particularly as the elderly population increases [1]. Currently, cataract surgery is one of the most common operating procedures worldwide, and its main purpose is to improve vision by replacing the cataractous lens with an intraocular lens (IOL). As IOL technology has advanced substantially, optimal distance vision after cataract surgery has been taken for granted, and patients have begun to expect adequate near and intermediate vision without spectacles. To satisfy these expectations, advances in multifocal IOL technology have aimed to achieve maximal visual performance at all distances after IOL implantation. Nevertheless, multifocal IOLs are associated with the risk of decreased contrast sensitivity and the occurrence of photic phenomena, glare, and halos [2–4]. Multifocal IOLs still require accurate patient selection and are limited in patients with concomitant eye diseases. In particular, patients with epiretinal membrane (ERM), a condition that causes a thin, fibrous layer to grow on the surface of the retina, are poor candidates for multifocal IOLs due to the decreased predictability of spherical power, ultimate contrast sensitivity, potential metamorphopsia, and increased risk for post-operative cystoid macular oedema and lower visual acuity gain [5].

For these reasons, there have been many attempts to develop IOLs that can satisfy the intermediate visual demands of cataract patients who are unable to be the candidates for multifocal IOLs because of unwanted dysphotopsia of multifocality. From this background, a new innovative monofocal IOL, Tecnis Eyhance ICB00 (Johnson & Johnson Vision Care, Jacksonville, FL, USA), has been developed to provide patients with better vision at intermediate distances while ensuring distance visual acuity comparable with standard monofocal IOLs by its unique continuous power gradient increasing from the periphery to the centre [6, 7]. In addition, the Eyhance IOL should not compromise contrast sensitivity or cause more photic nuisance than multifocal and standard monofocal IOLs do [8]. Through these advantages, the Eyhance IOL is expected to widen the range of patients who can benefit from improved intermediate vision. However, the clinical features of the Eyhance IOL have not been confirmed in patients with ERM.

To investigate the effectiveness of this advanced IOL in patients with cataracts and other diseases that threaten vision, we designed a prospective study involving the Eyhance IOL in combined cataract and ERM surgery. We compared the visual outcomes of the Eyhance IOL with those of a standard monofocal IOL (Tecnis ZCB00 IOL, Johnson & Johnson Vision Care) in terms of visual acuity, refractory outcomes, contrast sensitivity, and metamorphosis. A novel quantitative method equipped in an electrophysiological testing machine (MonPack One®; Metrovision, Perenchies, France) was also applied to evaluate metamorphopsia.

Materials and Methods

This prospective, non-randomized, comparative study included patients who presented with symptomatic visual disturbance or distortion because of cataract and ERM and underwent combined cataract and vitreoretinal surgery with implantation of either a Tecnis Eyhance ICB00 IOL or a Tecnis ZCB00 IOL between August 2021 and August 2022. This study was conducted at a single centre (Dongtan Sacred Heart Hospital, Hwaseong City, Korea) in accordance with the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board of Dongtan Sacred Heart Hospital.

The inclusion criteria were as follows: age over 50 years, presence of subjective visual disturbance or distortion due to the cataract and idiopathic ERM, best corrected visual acuity from 1 logMAR to 0.1 logMAR, and preoperative corneal astigmatism of 1.00 dioptre (D) or less. Cases of foveal-attached type ERM (ERM involving fovea) [9] confirmed by optical coherence tomography (OCT) (Spectralis; Heidelberg Engineering, Heidelberg, Germany) were included in this study. The exclusion criteria were a history of ocular surgery for trauma, secondary ERM (e.g., retinal detachment, uveitis), additional macular and retinal pathology such as central serous chorioretinopathy, diabetic macular oedema, macular hole, macular schisis, degenerative myopia, inherited retinal diseases (e.g., Stargardt's disease, retinitis pigmentosa), diabetic retinopathy, glaucoma or intraocular pressure >21 mm Hg, and diagnosis of corneal irregularity or abnormality. Every patient was given detailed information about the advantages and disadvantages of IOLs and was asked to provide written informed consent. In cases of refusal to participate, a phacovitrectomy was carried out, during which a standard monofocal IOL (Tecnis ZCB00 IOL) was implanted. Patients who chose to have the Tecnis ZCB00 IOL implanted were categorized as the control group.

All surgical procedures were performed by the same expert surgeon (HIH) using retrobulbar or general anaesthesia. Clear corneal incision phacoemulsification and sutureless 25-G pars plana vitrectomy (PPV) with the Eva vitrectomy system (DORC Inc., Zuidland, The Netherlands) was performed in all patients. After anaesthesia, we inserted 25-G valved trocars 3.5 mm posterior to the corneal limbus in the inferotemporal (infusion line), superonasal, and superotemporal quadrants. Before vitrectomy, routine phacoemulsification surgery with a 2.8-mm clear corneal incision in the superior quadrant was performed, and the IOL was inserted into the bag. Sequentially, the vitreoretinal operative procedure was performed, including removal of the posterior hyaloid membrane, ERM, and internal limiting membrane (ILM) assisted by triamcinolone acetonide and Brilliant Blue G dye (Geuder, Heidelberg, Germany). After staining the ILM with Brilliant Blue G, ILM peeling was performed either at the same time as or after ERM removal using intraocular forceps (25-G Grieshaber Revolution DSP; Alcon Laboratories, Fort Worth, TX,

USA). The rhexis technique was employed in all cases within the arcade. Scleral compression was performed during peripheral vitrectomy to identify possible retinal breaks or degeneration. Fluid/air exchange and the insertion of silicone oil, gas, or air were employed at the surgeon's discretion or in response to complications necessitating these interventions. If not indicated, we proceeded with the filling of balanced salt solution plus (BSS Plus, Alcon Laboratories, Fort Worth, TX, USA) at the end of surgery.

Before surgery, all patients who met the inclusion criteria underwent a comprehensive preoperative ophthalmic examination that included the measurement of uncorrected and corrected visual acuity at 4 m distance, slit-lamp biomicroscopy, Goldmann applanation tonometry, manifest refraction, corneal topography, optical biometry, fundus examination, and macular OCT. The refractive power of the IOL to be implanted was based on biometry data assessed using IOL Master 500 (Carl Zeiss Meditec AG, Jena, Germany), and different formulas were used based on the patient's axial length (Holladay 1 and Barrett universal II formula for axial lengths >22.0 mm and <25.0 mm and Hoffer Q, Kane, and Barrett universal II formula for axial lengths ≤22.0 mm). The selected IOL power was aimed at achieving the predicted post-operative refraction closest to emmetropia. For each patient, an arithmetic mean of the IOL power values provided by each formula was calculated, and the final IOL power was chosen based on this calculation [10–13].

Monocular visual acuities were measured 6 months post-operatively, including corrected and uncorrected distance visual acuity (CDVA, UCDVA), uncorrected intermediate visual acuity (UCIVA), and uncorrected near visual acuity (UCNVA). Early Treatment Diabetic Retinopathy Study (ETDRS) charts (Precision Vision, La Salle, IL, USA) were used to measure distance visual acuity at 4 m, and the Sloan ETDRS Format Near Vision Chart (Precision Vision) was used to measure intermediate and near visual acuity at 66 cm and 40 cm, respectively. All visual acuities were measured under photopic conditions with 100% contrast. For statistical analysis, the values of the measured visual acuities were converted to logarithm of the minimum angle of resolution (logMAR).

Six months before and after surgery, metamorphopsia was recorded using a MonPack vision monitoring system (Metrovision) and the procedure was described in detail in the previous study of Lee et al. [14]. The metamorphopsia test is similar to the automated visual field perimetry examination (Fig. 1a). The total field was consisted of 21 subfields on a dark blue background. Local patterned stimuli consisted of a 4 × 4 grid pattern, which was presented at each subfield on the monitor with a pseudorandom sequence (Fig. 2b). The patient holds a response button, focuses on a central red gaze point, and presses the button when they recognize a grid pattern with straight lines. The outermost line of each grid represents a range of 10° in each direction, with each line spacing indicating a difference of 1°, and each inspection point located 4° away from the next point. Three tests are performed for each subfield: one with a curved pattern to confirm the reliability of the test, and two with straight line patterns to detect any metamorphopsia in the patient. The test programme provided a standardized report, including a map of the probability of altered locations and the total percentage of locations with alternations (Fig. 3c). A green point indicated if the patient pressed the button twice in the absence of distortion, a pink point indicated a single response for the absence of distortion, and a red point indicated if the patient did not press the button, meaning that the patient recognizes distortions in all presented patterns. The total percentage of locations with metamorphopsia was automatically calculated and represented as a percentage of alternation in the reporting chart. We defined this percentage of alternations as the M score. At post-operative 6 months, contrast sensitivity examination was performed under both photopic and mesopic conditions. Monocular corrected contrast sensitivity was examined using vertical sinusoidal bars at various spatial frequencies. A low-contrast bar was first presented, and then the contrast of each bar was progressively increased. The first point at which the patient recognized the grating bar was recorded. The contrast sensitivity examination was performed at 0.6, 1.1, 2.2, 3.4, 7.1, and 14.2 cycles/degree (cpd) spatial frequencies and illumination levels of 0–30 decibels (dB).

Spectralis OCT was used to obtain a spectral-domain OCT image with a raster scan divided in 31 B-scans at 30° × 25° centred on the fovea. Through an automatic real-time function using the eye-tracking system in this instrument, 25 frames were obtained from the same scanning location and averaged to improve the signal-to-noise ratio, creating one B-scan. Central macular thickness (CMT) was calculated using the automated software contained within the OCT machine through cube scan images. The retinal wrinkling ratio was defined as the value measured by dividing the length of the inner boundary on the outer nuclear layer by the length of the retinal pigment epithelium layer [14]. A single reader (GSJ), who was unknown regarding the patient's detail, manually calculated the lengths of the inner boundary on the outer nuclear layer and the retinal pigment epithelium layer using ImageJ (National Institutes of Health, Bethesda, MD, USA) (Fig. 1b). The correlation of the retinal wrinkling ratio on the OCT image with the percentage of alternation from the metamorphopsia test was calculated to investigate whether this correlation was affected by the presence of cataracts and the type of IOL.

The sample size was calculated based on the analyses of UCIVA at 6 months post-operatively. A sample size of 29 patients per group was found to be necessary to find a clinically significant difference of 0.1 logMAR in the UCIVA at post-operative 6 months with 80% power (α = 0.05, SD = 1.5). The mean CDVA, UCDVA, UCIVA, UCNVA, and the corresponding standard deviation of these values were calculated, and the normality of the data samples was assessed by the Shapiro-Wilk test. When the data distributions were normal in both groups, Student's *t* test was used for comparison. If the data were not normally distributed, the Mann-Whitney U test was used. To evaluate the relationship between the percentage of alternation (M score) and the retinal wrinkling ratio, Pearson's or Spearman's rank correlation coefficient was used. Fisher's z-test was used to compare the correlation coefficients between IOLs. Furthermore, analysis of covariance was used to investigate whether the degree of metamorphopsia varied according to the IOL type. Retinal wrinkling ratio was used as a covariate. From this analysis, we investigated whether there was any difference between IOLs in relation to the percentage of distortion.

Results

There were 65 eyes of 65 patients included in this study. There were 33 and 32 patients in the Eyhance ICB00 group (group 1) and the Tecnis ZCB00 group

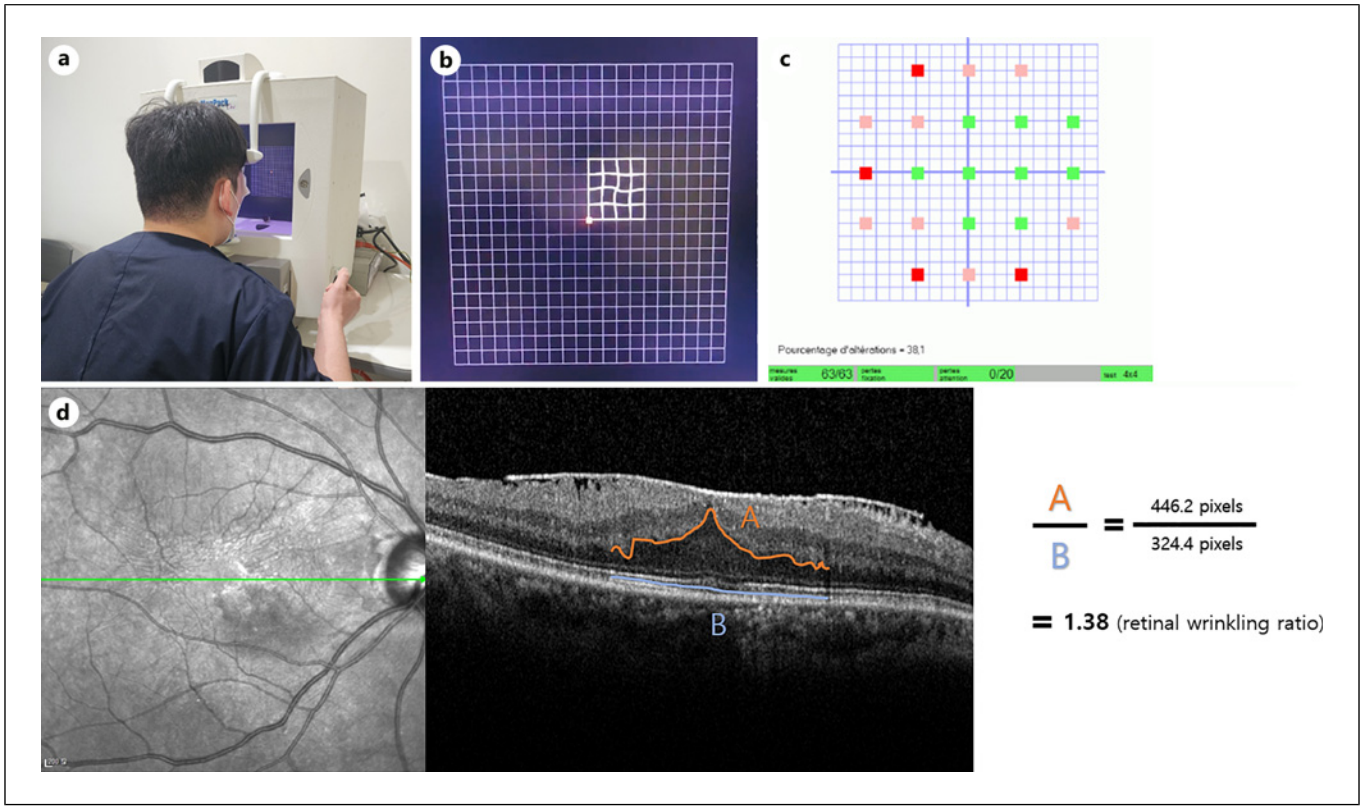

Fig. 1. a The novel metamorphopsia test is similar to an automatic visual field perimetry test. **b** A pseudorandom sequence was used to display a white stimulation comprising a 4 × 4 grid pattern of straight or curved lines on a dark blue background in each subfield of the monitor. **c** Reporting chart of metamorphopsia test. Total percentage of locations with alterations is automatically calculated and presented as percentage of alternation. **d** Methodology of calculating the retinal wrinkling ratio on horizontal optical computed tomography scan. The retinal wrinkling ratio is measured by dividing the length of the inner boundary on the outer nuclear layer (ONL) by the length of the retinal pigment epithelium (RPE) layer.

(group 2), respectively. Table 1 shows the preoperative characteristics of the patients in each group. There were no significant differences in terms of age, sex, preoperative and targeted spherical equivalent (SE), axial length, monocular CDVA, preoperative keratometric cylinder, CMT, preoperative percentage of alternation from metamorphopsia test, or preoperative retinal wrinkling ratio between the two groups. All patients who underwent cataract surgery and vitrectomy did not experience any complications during or after the surgery. None of the patients required gas tamponade for the vitreous cavity.

The mean CDVA of all 65 eyes before surgery was 0.50 ± 0.20 logMAR, which increased significantly to 0.11 ± 0.12 logMAR at 6 months after surgery ($p < 0.001$, Student's *t* test). At baseline, the mean CMT of 65 eyes was 392.34 ± 103.22 μm, which decreased significantly to 322.85 ± 71.12 μm ($p < 0.001$, Student's *t* test). The mean retinal wrinkling ratios of the 65 eyes at baseline and at 6 months after surgery were 1.20 ± 0.19 and 1.07 ± 0.07, respectively. The mean M scores from the metamorphopsia test before and after surgery were 27.08 ± 24.97% and 9.51 ± 9.91%, respectively. There were significant differences before and after surgery in both the mean retinal wrinkling ratio and the degree of metamorphopsia ($p < 0.001$, Student's *t* test).

Table 2 shows the post-operative characteristics of the patients in each group. The mean CDVA before surgery in groups 1 and 2 was 0.49 ± 0.22 logMAR and 0.52 ± 0.17 logMAR, respectively. The mean CDVA of groups 1 and 2 improved to 0.12 ± 0.14 and 0.10 ± 0.10, respectively, at 6 months after combined cataract surgery and vitrectomy. CDVA at 6 months post-operation improved in both groups compared to preoperative CDVA ($p < 0.001$, Student's *t* test). The preoperative CMT in groups 1 and 2 was 392.45 ± 100.55 μm and 400.34 ± 107.36 μm, respectively, which decreased at 6 months after surgery to 325.42 ± 72.85 μm in group 1 and 340.50 ± 69.62 μm in group 2 ($p < 0.001$, Student's *t* test), respectively. The

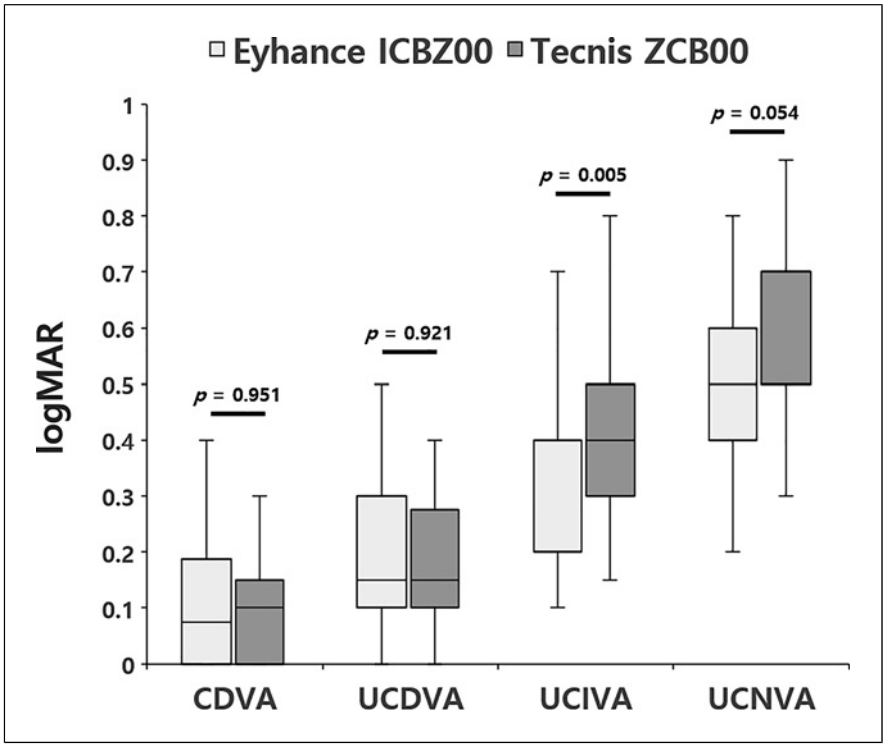

Fig. 2. Comparative chart presenting the mean CDVA, UCDVA, UCIVA, and UCNVA values of the Eyhance IOL and Tecnis IOL with their standard deviations. CDVA, corrected distance visual acuity; UCDVA, uncorrected distance visual acuity; UCIVA, uncorrected intermediate visual acuity; UCNVA, uncorrected near visual acuity; IOL, intraocular lens.

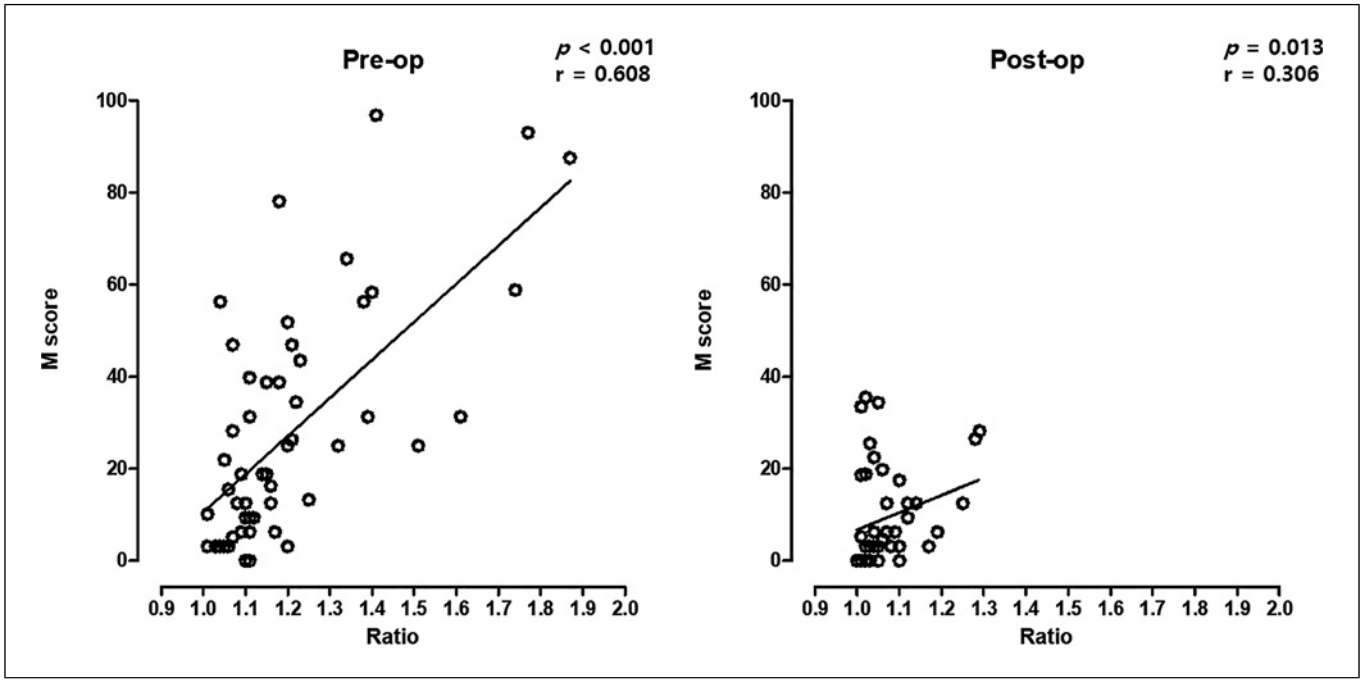

Fig. 3. Correlation analysis of retinal wrinkling ratio and M score. Left: before surgery. Right: 6 months after surgery. Spearman's rank correlation coefficient (r) and *p* values for the slope of the regression line are reported.

Table 1. Preoperative characteristics of patients in the two intraocular lens groups (mean ± SD)

	Eyhance ICBZ00 (n = 33)	Tecnis ZCB00 (n = 40)	p value*
Age, years	59.42±8.55	62.40±13.39	0.136
Sex (male/female)	12/21	14/26	0.904
SE, D	1.04±4.61	1.22±5.30	0.963
Cylinder, D	−0.66±0.36	−0.63±0.32	0.802
Axial length	23.91±1.28	24.12±1.83	0.790
Preoperative CDVA (logMAR)	0.94±0.93	0.93±0.83	0.798
Preoperative CMT, μm	402.10±167.79	354.92±139.48	0.511
Targeted SE, D	−0.24±0.13	−0.30±0.08	0.068

SE, spherical equivalent; D, dioptre; CDVA, corrected distant visual acuity; CMT, central macular thickness. *Mann-Whitney U test.

Table 2. Post-operative characteristics of patients in the two intraocular lens groups (mean ± SD)

	Eyhance ICBZ00 (n = 33)	Tecnis ZCB00 (n = 40)	p value*
Operation time, min	49.39±9.13	48.53±20.66	0.141
Post-operative CMT, μm	301.33±80.56	325.60±83.32	0.017
Post-operative SE, D	−0.35±0.49	−0.47±0.52	0.963
Post-operative CDVA (logMAR)	0.12±0.14	0.10±0.10	0.951
Post-operative UCDVA (logMAR)	0.18±0.14	0.17±0.11	0.921
Post-operative UCIVA (logMAR)	0.30±0.17	0.40±0.14	0.005
Post-operative UCNVA (logMAR)	0.55±0.21	0.60±0.18	0.054

CMT, central macular thickness; SE, spherical equivalent; D, dioptre; CDVA, corrected distant visual acuity; UCDVA, uncorrected distant visual acuity; UCIVA, uncorrected intermediate visual acuity; UCNVA, uncorrected near visual acuity. *Mann-Whitney U test.

mean time required for combined cataract surgery and vitrectomy was 47.27 ± 11.57 min in group 1 and 48.90 ± 15.80 min in group 2 (p = 0.677, Mann-Whitney U test). Vitrectomy-related iatrogenic retinal tear did not develop in either group, and there were no patients using tamponade including gas or silicone oil.

There was no significant relationship between groups in terms of post-operative CMT, SE, CDVA, UCDVA, UCNVA, M score, or retinal wrinkling ratio, whereas the UCIVA value at 6 months after surgery was significantly higher in group 1 (p = 0.005, Mann-Whitney U test). The post-operative UCIVA was 0.30 ± 0.17 logMAR and 0.40 ± 0.14 logMAR in groups 1 and 2, respectively. Figure 3 shows a comparative chart of the CDVA, UCDVA, UCIVA, and UCNVA values of the two different groups.

The mean mesopic and photopic contrast sensitivity values of groups 1 and 2 are shown in Table 3. There were no significant differences between groups in terms of mesopic and photopic contrast sensitivity for any spatial frequency (p > 0.05, Mann-Whitney U test).

Figures 3 and 4 show the correlation of the retinal wrinkling ratio with the M scores from the metamorphopsia test by Spearman's rank correlation coefficients according to ERM removal and IOL type. The retinal wrinkling ratio was significantly correlated with the M scores from the metamorphopsia test, both preoperatively (p < 0.001, r = 0.608) and post-operatively (p = 0.013, r = 0.306). The post-operative retinal wrinkling ratio also showed a significant correlation with the post-operative M scores from the metamorphopsia test in group 1 (p = 0.024, r = 0.349) and group 2 (p = 0.041, r = 0.313). The correlation coefficients did not differ significantly between groups by Fisher's z-test (z value = 0.155, p = 0.877). In addition, when the retinal wrinkling ratio was set as a covariate in the analysis of covariance, the degree of metamorphopsia was not significantly related to the type of IOL (p = 0.969).

Table 3. Comparison of contrast sensitivity values between patient and control groups

Spatial frequency (cpd)	0.6	1.1	2.2	3.4	7.1	14.2
Photopic condition						
Eyhance ZCB00 (33 eyes)	14.88±2.14	17.70±2.16	18.30±2.31	18.27±3.20	15.39±4.37	6.24±4.29
Tecnis ICB00 (32 eyes)	14.97±2.80	17.28±3.74	18.38±3.33	17.88±3.27	14.28±4.75	6.38±4.73
p value*	0.778	0.942	0.846	0.550	0.584	0.654
Mesopic condition						
Eyhance ZCB00 (33 eyes)	14.33±2.14	17.70±2.16	18.30±2.31	18.27±3.20	15.39±4.37	6.24±4.29
Tecnis ICB00 (32 eyes)	14.97±2.80	17.28±3.74	18.38±3.33	17.88±3.27	14.28±4.75	6.38±4.73
p value*	0.258	0.984	0.369	0.559	0.429	0.963

*Mann-Whitney U test.

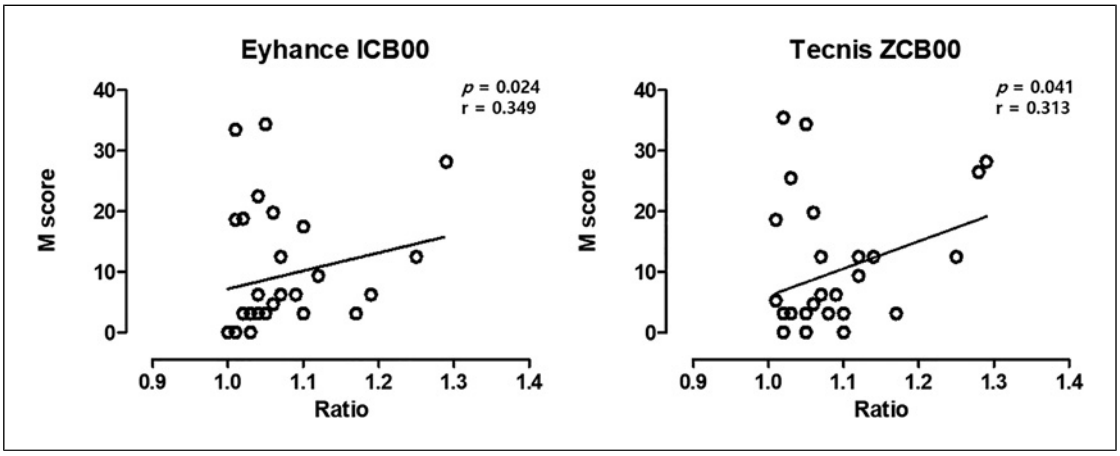

Fig. 4. Correlation analysis of retinal wrinkling ratio and M score (left) in the Eyhance ICB00 IOL group and (right) in the Tecnis ZCB00 IOL group. Spearman's rank correlation coefficient (r) and *p* values for the slope of the regression line are reported. IOL, intraocular lens.

Discussion

In modern life, intermediate vision is becoming a growing concern owing to the increased use of tablets and computers, and it is important for walking up the stairs or looking at a car dashboard [15, 16]. Thus, more recent IOLs, including trifocal and extended depth-of-focus (EDOF) IOLs, have been introduced to promise intermediate vision by increasing the depth of field based on diffractive technology. However, patients with any type of macular disease are considered poor candidates for these newly developed IOLs because of the compromised predictability of refractory power, post-operative contrast sensitivity, and potential metamorphopsia [5]. Standard IOLs provide only monofocal vision because of their aspheric features [17, 18]. However, the Eyhance ICB00 can increase intermediate vision because of its unique design in which there is a thickness difference between the central and peripheral areas. This difference increases the depth of focus by changing the power distribution from the periphery to the centre, which improves the visual acuity at intermediate distances [7, 19]. While prior research has already shown the safety and effectiveness of the new IOL [18, 20–22] and anticipated a noteworthy improvement in the quality of life for patients undergoing combined cataract and vitreoretinal surgery, it is worth noting that only a few studies have specifically investigated the outcomes of such combined vitreoretinal surgery when the Eyhance IOL was employed [23–25].

When we compared the post-operative results 6 months after combined cataract surgery and vitrectomy in 33 patients with the Eyhance ICB00 IOL and 32

patients with the Tecnis ZCB00 IOL, there were no significant differences in terms of CMT, SE, CDVA, UCDVA, or UCNVA, while eyes with advanced IOLs had a significantly higher UCIVA. Furthermore, the photopic and mesopic contrast sensitivities were similar between groups. The mean values of all measured visual acuities and contrast sensitivities were lower than those reported in previous studies [20, 22, 26], suggesting an effect of the loss of ERM-associated macular function. Despite compromised macular function by ERM, the Eyhance IOL showed superior visual performance to standard monofocal IOL in patients who underwent simultaneous cataract and vitreoretinal surgery, providing significant improvement in intermediate vision while showing similar distance vision and contrast sensitivity. Moreover, it is important to note that there was no discernible correlation between the enhancement in intermediate vision and the refractive outcomes. Despite the lack of statistical significance between the two groups, the SEs in the standard IOL group were more myopic than those in the Eyhance group 6 months post-surgery, underscoring that the refractive results did not align with the substantial improvement in UCIVA achieved with the Eyhance ZCB00 IOL. In other studies utilizing the Eyhance IOL for combined cataract and vitrectomy surgery, similar results are observed, further emphasizing the exceptional visual performance of the Eyhance IOL, particularly at intermediate distances [23–25].

A notable challenge associated with combined surgeries lies in the inherent unpredictability of post-operative refractive errors, a phenomenon well-documented in various studies, including myopic shifts in post-operative refraction [27]. Precisely estimating refractive power is a critical factor in the success of cataract surgery, especially when dealing with patients who may require multifocal IOL implantation [28]. Failure to attain emmetropia in post-operative refractive power can result in patient dissatisfaction stemming from issues like blurred vision and halos. Consequently, the introduction of multifocal IOLs for patients undergoing combined cataract and vitreoretinal surgery has been approached with caution. In our study, post-operative refraction exhibited a slight myopic tendency and a greater standard deviation than the predicted refraction, primarily attributed to the myopic shift associated with the combined cataract and vitrectomy procedure [27]. This myopic shift could potentially pose challenges for patients with multifocal IOLs, leading to discomfort related to issues such as blurred vision and compromised contrast sensitivity. However, it is noteworthy that in our study, despite not achieving emmetropia in post-operative refractive power, the Eyhance IOL provided satisfactory visual outcomes by preserving intermediate vision and contrast sensitivity. Importantly, a study by Unsal et al. [20] highlighted the Eyhance IOL's greater tolerance for residual refractive errors compared to standard monofocal IOLs.

Another reason for hesitation in the use of multifocal IOL in combined cataract and PPV is that unexpected situations can be encountered during vitrectomy with multifocal IOLs. Multiple concentric optical rings with different dioptres can induce various optical limitations during vitrectomy [29, 30]. Yoshino and Inoue reported difficulties in fundus visualization during PPV using a diffractive multifocal IOL. In contrast, Velasco et al. [31] reported no perioperative difficulty related to diffractive multifocal IOLs, but they did not recommend simultaneous cataract and vitrectomy surgery with diffractive rings or lenses. The Eyhance IOL is also an EDOF IOL, but instead of using a diffractive structure, it adds a high-order aspheric structure in the centre location to extend the depth of focus [26, 32, 33]. Because of this, in a study using a model eye, the Eyhance IOL not only did not reduce macular visibility but showed better macular visibility during vitrectomy than a multifocal EDOF IOL with diffraction structures [34]. This study also reported that the image contrast of this enhanced monofocal IOL was higher than or equal to that of a standard monofocal IOL. There was no significant difference in operation time between groups in our study, suggesting that the high-order aspheric structure of the Eyhance IOL did not affect fundus visualization difficulty during PPV for ERM. The surgeon who performed the surgery also did not experience any difficulty in visualizing the fundus with the Eyhance IOL during combined cataract and PPV and accomplished the surgery without complications.

Metamorphopsia is the most common symptom in patients with ERM [35]. A quantified assessment of metamorphopsia is important for estimating disease progress and determining treatment outcomes in patients with ERM [36], but there is no established objective method. A novel test for evaluating metamorphopsia was introduced to assess these issues, which is similar to the automatic visual field test. Shinoda et al. [14] already reported the reproducibility of this new metamorphopsia test, and Lee et al. [37]

demonstrated that the degree of metamorphopsia investigated by this test is significantly correlated with the retinal structure on OCT. Previous studies have shown a significant correlation between wrinkling or oedematous changes in the inner retinal layer and the degree of metamorphopsia, considering these abnormal changes in the inner retinal layer as a potential indicator for ERM surgery in terms of managing the symptoms of metamorphopsia [38–40]. However, the M-chart has been mostly used in previous studies to quantify the degree of metamorphopsia symptoms in patients with ERM. In this study, we first used a novel metamorphopsia test to evaluate the pre- and post-operative degree of metamorphopsia symptoms and correlated them with inner retinal structure; consistent with previous studies, the degree of metamorphopsia was decreased after successful vitrectomy and a significant correlation was observed between the retinal wrinkling ratio and metamorphopsia at all timepoints. Furthermore, there was no significant difference between IOLs regarding metamorphopsia evaluation. From these results, we demonstrated that the novel metamorphopsia test is a quick and easily feasible test to evaluate metamorphopsia in ERM surgery, and implantation of the Eyhance IOL did not interfere with the assessment of metamorphopsia using this novel method.

This study had several limitations. Due to the recent release of the Eyhance IOL, the short follow-up period and a small sample size group were limitations of our study. Additionally, our study did not include patients with multifocal IOLs. Altun et al. [30] reported an increased risk of iatrogenic retinal break in eyes undergoing vitrectomy via multifocal IOLs, and Auffarth et al. [26] reported a higher incidence of central macular oedema in the Eyhance IOL group than in the conventional monofocal IOL group. However, in our study, there were no intra- or post-operative complications in either group, including iatrogenic retinal tear, central macular oedema, or ERM recurrence. This could be due to the small number of patients and short follow-up period. Because of the potential for selection bias due to the lack of randomization, the limited sample size, a relatively brief follow-up period, and the potential impact of uncontrolled confounding variables, it is advisable to employ more rigorous study designs, such as randomized controlled trials. The long-term randomized clinical trials that encompass a variety of monofocal and multifocal IOLs are warranted to enhance our understanding of how IOL selection influences the results of ERM surgery.

Our study used the Eyhance ICB00 IOL for combined cataract and vitrectomy surgeries. Compared with a standard monofocal IOL, the post-operative UCIVA improved without compromising the distance visual acuity, contrast sensitivity, or operation time. A novel method for evaluating metamorphopsia was applied in this study, which was found to be a fast and reliable method of quantifying visual distortion in patients undergoing ERM surgery and can provide automated monitoring of visual distortion before and after ERM surgery. Furthermore, the Eyhance IOL did not influence this novel method. As a result, the enhanced monofocal IOL can be recommended for ERM patients undergoing combined cataract surgery and vitrectomy, which might improve patients' quality of life.

Statement of Ethics

The study was approved by the Institutional Review Board/Ethics Committee of Dongtan Sacred Heart Hospital (IRB no. HDT 2021-05-004). All procedures performed in studies involving human participants were conducted in accordance with the Ethical Standards of the Institutional and/or National Research Committee, as well as with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Written informed consent was obtained from all individual participants included in the study.

Conflict of Interest Statement

The authors declare that there are no conflicts of interest.

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Author Contributions

In Hwan Hong and Se Hyun Choi designed and conducted the study. In Boem Chang and Gang Seok Jeon collected the data. In Hwan Cho and Dae Joong Ma analysed and interpreted the data. Se Hyun Choi, In Boem Chang, Dae Joong Ma, In Hwan Cho, Gang Seok Jeon, and In Hwan Hong prepared, reviewed, and approved the manuscript.

Data Availability Statement

Data are not publicly available due to ethical reasons. Further enquiries can be directed to the corresponding author.

References

1 Hashemi H, Pakzad R, Yekta A, Aghamirsalim M, Pakbin M, Ramin S, et al. Global and regional prevalence of age-related cataract: a comprehensive systematic review and meta-analysis. Eye. 2020;34(8):1357–70. doi: 10.1038/s41433-020-0806-3.

2 Breyer DR, Kaymak H, Ax T, Kretz FT, Auffarth GU, Hagen PR. Multifocal intraocular lenses and extended depth of focus intraocular lenses. Asia Pac J Ophthalmol. 2017;6(4):339–49. doi: 10.22608/APO.2017186.

3 Shen Z, Lin Y, Zhu Y, Liu X, Yan J, Yao K. Clinical comparison of patient outcomes following implantation of trifocal or bifocal intraocular lenses: a systematic review and meta-analysis. Sci Rep. 2017;7(1):45337–9. doi: 10.1038/srep45337.

4 Mencucci R, Favuzza E, Caporossi O, Savastano A, Rizzo S. 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. Graefe's Archive Clin Exp Ophthalmol. 2018;256(10):1913–22. doi: 10.1007/s00417-018-4052-3.

5 Hardin JS, Gauldin DW, Soliman MK, Chu CJ, Yang YC, Sallam AB. Cataract surgery outcomes in eyes with primary epiretinal membrane. JAMA Ophthalmol. 2018;136(2):148–54. doi: 10.1001/jamaophthalmol.2017.5849.

6 Mencucci R, Cennamo M, Venturi D, Vignapiano R, Favuzza E. Visual outcome, optical quality, and patient satisfaction with a new monofocal IOL, enhanced for intermediate vision: preliminary results. J Cataract Refract Surg. 2020;46(3):378–87. doi: 10.1097/j.jcrs.0000000000000061.

7 Tognetto D, Cecchini P, Giglio R, Turco G. Surface profiles of new-generation IOLs with improved intermediate vision. J Cataract Refract Surg. 2020;46(6):902–6. doi: 10.1097/j.jcrs.0000000000000215.

8 Johnson & Johnson Vision. Delivering intermediate vision: the new TECNIS Eyhance Monofocal IOL. The Ophthalmologist. 2019.

9 Hwang JU, Sohn J, Moon BG, Joe SG, Lee JY, Kim JG, et al. Assessment of macular function for idiopathic epiretinal membranes classified by spectral-domain optical coherence tomography. Invest Ophthalmol Vis Sci. 2012;53(7):3562–9. doi: 10.1167/iovs.12-9762.

10 Holladay JT, Prager TC, Chandler TY, Musgrove KH, Lewis JW, Ruiz RS. A three-part system for refining intraocular lens power calculations. J Cataract Refract Surg. 1988;14(1):17–24. doi: 10.1016/s0886-3350(88)80059-2.

11 Barrett GD. An improved universal theoretical formula for intraocular lens power prediction. J Cataract Refract Surg. 1993;19(6):713–20. doi: 10.1016/s0886-3350(13)80339-2.

12 Hoffer KJ. The Hoffer Q formula: a comparison of theoretic and regression formulas. J Cataract Refract Surg. 1993;19(6):700–12. doi: 10.1016/s0886-3350(13)80338-0.

13 Connell BJ, Kane JX. Comparison of the Kane formula with existing formulas for intraocular lens power selection. BMJ Open Ophthalmol. 2019;4(1):e000251. doi: 10.1136/bmjophth-2018-000251.

14 Lee JW, Park SY, Kim PS, Cho IH, Kim HD. Correlations among metamorphopsia test scores, optical coherence tomography findings and multifocal electroretinogram responses in epiretinal membrane patients. Doc Ophthalmol. 2021;142(3):293–304. doi: 10.1007/s10633-020-09803-x.

15 Bellucci R. Multifocal intraocular lenses. Curr Opin Ophthalmol. 2005;16(1):33–7. doi: 10.1097/00055735-200502000-00006.

16 Rocha KM. Extended depth of focus IOLs: the next chapter in refractive technology? Incorporated Thorofare, NJ: SLACK; 2017. p. 146–9.

17 de Silva SR, Evans JR, Kirthi V, Ziaei M, Leyland M. Multifocal versus monofocal intraocular lenses after cataract extraction. Cochrane Database Syst Rev. 2016;12(12). doi: 10.1002/14651858.CD003169.pub4.

18 Unsal U, Sabur H. Comparison of new monofocal innovative and standard monofocal intraocular lens after phacoemulsification. Int Ophthalmol. 2021;41(1):273–82. doi: 10.1007/s10792-020-01579-y.

19 Vega F, Millán MS, Gil MA, Garzón N. Optical performance of a monofocal intraocular lens designed to extend depth of focus. J Refract Surg. 2020;36(9):625–32. doi: 10.3928/1081597X-20200710-01.

20 Unsal U, Sabur H. Comparison of new monofocal innovative and standard monofocal intraocular lens after phacoemulsification. Int Ophthalmol. 2021;41(1):273–82. doi: 10.1007/s10792-020-01579-y.

21 Cinar E, Bolu H, Erbakan G, Yuce B, Aslan F, Fece M, et al. Vision outcomes with a new monofocal IOL. Int Ophthalmol. 2021;41(2):491–8. doi: 10.1007/s10792-020-01599-8.

22 Lopes D, Loureiro T, Carreira R, Rodrigues BS, Cardoso JN, Campos P, et al. Comparative evaluation of visual outcomes after bilateral implantation of an advanced or conventional monofocal intraocular lens. Eur J Ophthalmol. 2021;32(1):229–234. doi: 10.1177/1120672121995343.

23 Choi SH, Lee HS, Chang IB, Ma DJ, Cho IH, Lee SJ, et al. Evaluation of a new monofocal intraocular lens in patients undergoing cataract and vitrectomy surgery for idiopathic macular hole. Curr Eye Res. 2023;48(10):904–10. doi: 10.1080/02713683.2023.2229542.

24 Giansanti F, Dragotto F, Nicolosi C, Alonzo L, Cifarelli L, Franco FGS, et al. Enhancing intermediate vision in patients affected by epiretinal membrane treated by phacovitrectomy. J Clin Med. 2023;12(15):5016. doi: 10.3390/jcm12155016.

25 Park MJ, Lee HS, Chang IB, Hong IH. Improved intermediate visual function with new monofocal intraocular lens in combined cataract and vitrectomy surgery for retinal disease. Korean J Ophthalmol. 2023;37(5):401–8. doi: 10.3341/kjo.2023.0056.

26 Auffarth GU, Gerl M, Tsai L, Janakiraman DP, Jackson B, Alarcon A, et al. Clinical evaluation of a new monofocal IOL with enhanced intermediate function in patients with cataract. J Cataract Refract Surg. 2021;47(2):184–91. doi: 10.1097/j.jcrs.0000000000000399.

27 Sakamoto M, Yoshida I, Sodeno T, Sakai A, Masahara H, Maeno T. Postoperative refractive prediction error measured by optical and acoustic biometry after phacovitrectomy for rhegmatogenous retinal detachment without macular involvement. J Ophthalmol. 2019;2019:5964127. doi: 10.1155/2019/5964127.

28 Gibbons A, Ali TK, Waren DP, Donaldson KE. Causes and correction of dissatisfaction after implantation of presbyopia-correcting intraocular lenses. Clin Ophthalmol. 2016;10:1965–70. doi: 10.2147/OPTH.S114890.

29 Dias-Santos A, Costa L, Lemos V, Anjos R, Vicente A, Ferreira J, et al. The impact of multifocal intraocular lens in retinal imaging with optical coherence tomography. Int Ophthalmol. 2015;35(1):43–7. doi: 10.1007/s10792-014-0016-8.

30 Altun A. Comparing the effect of monofocal and multifocal intraocular lenses on macular surgery. J Ophthalmol. 2020;2020:1375298. doi: 10.1155/2020/1375298.

31 Arrevola-Velasco L, Beltran J, Gimeno MJ, Ortega-Usobiaga J, Druchkiv V, Llovet-Osuna F, et al. Visual outcomes after vitrectomy for epiretinal membrane in pseudophakic eyes with a diffractive trifocal intraocular lens: a retrospective cohort study. BMC Ophthalmol. 2022;22(1):39–10. doi: 10.1186/s12886-022-02273-6.

32 Alarcon A, Cánovas C, Koopman B, Weeber H, Auffarth GU, Piers PA. Enhancing the intermediate vision of monofocal intraocular lenses using a higher order aspheric optic. J Refract Surg. 2020;36(8):520–7. doi: 10.3928/1081597X-20200612-01.

33 Kang KH, Song MY, Kim KY, Hwang KY, Kwon YA, Koh K. Visual performance and optical quality after implantation of a new generation monofocal intraocular lens. Korean J Ophthalmol. 2021;35(2):112–9. doi: 10.3341/kjo.2020.1115.

34 Yoshikawa Y, Kanno J, Shinoda K, Makita J. Evaluation of macular visibility through a high-order aspheric intraocular lens using a simulated model eye. Medicine. 2022;101(41):e31018. doi: 10.1097/MD.0000000000031018.

35 Wong JG, Sachdev N, Beaumont PE, Chang AA. Visual outcomes following vitrectomy and peeling of epiretinal membrane. Clin Exp Ophthalmol. 2005;33(4):373–8. doi: 10.1111/j.1442-9071.2005.01025.x.
36 Bouwens MD, Van Meurs JC. Sine Amsler Charts: a new method for the follow-up of metamorphopsia in patients undergoing macular pucker surgery. Graefe's archive Clin Exp Ophthalmol. 2003;241(2):89–93. doi: 10.1007/s00417-002-0613-5.
37 Shinoda K, Ishida S, Kawashima S, Matsuzaki T, Yamada K, Katsura H. A new method for quantification of metamorphopsia in patients with epiretinal membrane. Jpn J Ophthalmol. 2000;44(4):424–7. doi: 10.1016/s0021-5155(00)00173-8.
38 Watanabe A, Arimoto S, Nishi O. Correlation between metamorphopsia and epiretinal membrane optical coherence tomography findings. Ophthalmology. 2009;116(9):1788–93. doi: 10.1016/j.ophtha.2009.04.046.
39 Cho KH, Park SJ, Cho JH, Woo SJ, Park KH. Inner-retinal irregularity index predicts postoperative visual prognosis in idiopathic epiretinal membrane. Am J Ophthalmol. 2016;168:139–49. doi: 10.1016/j.ajo.2016.05.011.
40 Alkabes M, Fogagnolo P, Vujosevic S, Rossetti L, Casini G, De Cillà S. Correlation between new OCT parameters and metamorphopsia in advanced stages of epiretinal membranes. Acta Ophthalmol. 2020;98(8):780–6. doi: 10.1111/aos.14336.