• Clinical Research •

Visual and refractive evaluation of two diffractive trifocal intraocular lens platforms with distant and near dominant light energy distributions

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Received: 2025-11-26 Accepted: 2026-06-24

Abstract

● **AIM:** To compare the visual, refractive, and optical performance of two diffractive trifocal intraocular lenses (IOLs) with analogous designs but different light distribution profiles.

● **METHODS:** A total of 54 eyes from 48 patients undergoing cataract surgery received either the Gemetric™ (GM; Hoya Surgical Optics, Singapore) or the Gemetric™ Plus (GMP; Hoya Surgical Optics) IOLs. Preoperative demographics were comparable between the two groups. Generalized estimating equations (GEE) were utilized for statistical analysis to adjust for inter-eye correlations.

● **RESULTS:** A total of 48 patients (54 eyes) were included in the analysis, of which 30 patients (33 eyes) received the GM IOL and 18 patients (21 eyes) the GMP IOL. The mean age was 59.6±6.1y (range: 48–72) in the GM group and 61.6±5.8y (range: 49–69) in the GMP group (P=0.339). At 3mo postoperatively, there were no statistically significant differences in uncorrected distance visual acuity (VA) and uncorrected near vision at 40 cm. However, the GM group showed statistically significantly better outcomes in corrected distance VA (P=0.003) and uncorrected intermediate VA at 66 cm (P=0.033). Conversely, uncorrected near VA at 33 cm was significantly superior in the GMP group (P=0.048). The objective assessment of optical quality showed improved distance and intermediate performance with the GM, while the GMP performed better at near, consistent with the patients' measured visual outcomes.

● **CONCLUSION:** Adjusting light distribution in otherwise identical trifocal IOLs results in distinct clinical and optical advantages, allowing surgeons to tailor IOL selection to patients' specific visual demands.

● **KEYWORDS:** defocus curve; intraocular lens; multifocal intraocular lens; optical bench testing; trifocal intraocular lens

DOI:10.18240/ijo.2026.10.11

Citation: Son HS, Yu SH, Koh K, Auffarth GU, Łabuz G. Visual and refractive evaluation of two diffractive trifocal intraocular lens platforms with distant and near dominant light energy distributions. *Int J Ophthalmol* 2026;19(10):1971-1977

INTRODUCTION

Today, various presbyopia-correcting intraocular lenses (IOLs) exist to provide functional unaided vision at multiple distances after cataract surgery[1-2]. Trifocal IOLs distribute incidence light energy to three separate focal points, enabling excellent vision at near, intermediate, and distant ranges[3-6]. While they currently achieve the maximal spectacle independence, trifocal optics are associated with higher incidence of photic phenomena due to the defocused image overlay causing the halo effects[7]. In contrast, extended-depth-of-focus (EDOF) IOLs create an elongated focus rather than separate multiple foci, thereby reducing dysphotopsia while achieving satisfactory uncorrected vision from far to intermediate distances. EDOF IOLs, however, underperform in near vision compared to trifocal lenses.

Given the advantages and potential drawbacks of each IOL type, different strategies have been proposed to minimize the spectacle dependence and maximize patient satisfaction. For example, implanting two different optic platforms, *e.g.,* a trifocal lens in the non-dominant eye and an EDOF lens in the dominant eye, is one such option. Termed a mix-and-match strategy, this asymmetric implantation technique attempts to

reinforce the advantages of each IOL and has been shown to achieve good outcomes[8-9]. Alternatively, a monovision approach with various combination of monofocal, mono-EDOF, EDOF, and diffractive multifocal lenses has also been demonstrated to provide satisfactory unaided vision across multiple distances[10-12].

Recent generation of trifocal IOLs offers another approach: the Gemetric (GM) family of trifocal IOLs (Hoya Surgical Optics, Singapore) comes with varying light distribution profiles, allowing a more personalized IOL selection depending on each patient's visual demands[13]. To be specific, the GM emphasizes higher light energy allocation to intermediate and distance foci, allowing reinforced vision in these distances, while the Gemetric Plus (GMP) directs more light energy to near distance[14-15]. Given such differences in light energy distribution, it remains to be explored whether bilateral implantation of GM or GMP provides satisfactory clinical outcomes or whether a mix-and-match strategy combining GM and GMP may be superior in achieving maximal spectacle independence. This study is part of a series of on-going clinical studies at our institute and aims to first compare the visual acuity and refractive outcomes after bilateral implantation of GM and GMP.

PARTICIPANTS AND METHODS

Ethical Approval This retrospective, comparative analysis was conducted in accordance with the principles of the Declaration of Helsinki. The Institutional Review Board of participating institution approved the study protocol (approval number: 2025-10-006). Because of the retrospective design, the requirement for informed consent was waived. All data were anonymized, and no patient-identifying information was included in the analysis.

Participants The study reviewed the medical records of consecutive patients who underwent cataract surgery with bilateral implantation of either the GM or GMP IOL between August 2024 and June 2025 at a tertiary eye hospital. Eligible participants were between 45 and 75 years of age with visually significant cataracts who came to the follow-up examination at 3mo postoperatively. Exclusion criteria were the presence of ocular comorbidities that may compromise the visual outcome, a history of ocular surgery or trauma, corneal astigmatism greater than 1.0 diopter (D), or a follow-up period of less than 3mo.

IOLs Used in Study Both IOLs are composed of hydrophobic acrylic material with a blue light-filtering chromophore and have an overall diameter of 13.0 mm with a 6.0 mm optic zone[15]. The base refractive power of the 6.0 mm optic provides distance correction, whereas intermediate and near vision are generated by a 3.2 mm central diffractive zone located on the anterior surface[15]. In both IOLs, the diffractive optics create an intermediate addition of 1.75 D and a near addition of 3.50 D at the IOL plane[15]. The key distinction between the two designs lies in the diffractive element configuration: the GMP allocates a greater proportion of light to the near focus, while the GM directs relatively more light to intermediate and distance foci[15].

IOL Power Calculation All biometric parameters, including anterior chamber depth (ACD), axial length (AL), white-to-white (WTW), and lens thickness (LT), as well as spherical aberration (SA) and root mean square (RMS) higher-order aberrations (HOA) measured at a 4-mm pupil, were measured using the Anterion® (Heidelberg Engineering, Heidelberg, Germany). The IOL power targeting emmetropia was calculated by the Barrett Universal II formula provided by Anterion® (Heidelberg Engineering, Heidelberg, Germany). The prediction error was attained by subtracting the targeted spherical equivalant (SE) from the observed SE at 3mo postoperatively[16]. The mean absolute error (MAE) was set as the mean absolute value of prediction error (PE)[17]. PE and MAE represented the accuracy measurements of the IOL power calculation in predicting refractive error.

Surgical Procedures All surgeries were conducted by a single experienced surgeon (Koh K). The primary corneal incision was made on the steep axis using a 2.8-mm clear corneal blade. A continuous curvilinear capsulorrhexis of approximately 5.2 mm in diameter was then created. Phacoemulsification was performed using the Whitestar Signature™ PRO system (Johnson & Johnson Vision, CA, USA), followed by implantation of the IOL into the capsular bag. At the conclusion of the procedure, stromal hydration was applied to seal the corneal wounds.

Visual Acuity Assessment and Defocus Curve Measurement Visual acuity (VA) was measured monocularly preoperatively as well as at 3mo postoperatively using the Early Treatment Diabetic Retinopathy Study (ETDRS) chart and expressed in logarithm of the minimum angle of resolution (logMAR) units. Uncorrected distance visual acuity (UDVA) and corrected distance visual acuity (CDVA) were evaluated at 6 m under photopic illumination (85 cd/m²). Uncorrected intermediate visual acuity (UIVA) was tested at 66 cm, and uncorrected near visual acuity (UNVA) was assessed at 40 cm and 33 cm under the same conditions.

At 3mo postoperatively, monocular defocus curves were obtained under photopic light conditions (85 cd/m^2)[18-19]. Monocular VAs were assessed at 6 m using ETDRS charts across the defocus range of +1.5 to −4.0 D[1]. Each defocus level was achieved by inserting a defocus lens at 0.5 D increments into a test frame.

Optical Bench Testing Contrary to clinical assessments, an *in vitro* analysis of an IOL's optical performance provides

Table 1 Preoperative parameters for patient groups mean±SD (range)

Parameters	Gemetric	Gemetric Plus	*P*
Patients/eyes, *n*	30/33	18/21	N/A
Female, *n* (%)	19 (63)	11 (61)	0.991
Age (y)	59.6±6.1 (48 to 72)	61.6±5.8 (49 to 69)	0.339
UDVA (logMAR)[a]	0.65±0.43 (0 to 1.7)	0.60±0.35 (0.1 to 1.2)	0.993
CDVA (logMAR)[a]	0.17±0.12 (0 to 0.4)	0.16±0.11 (0.1 to 0.3)	0.809
ACD (mm)	2.78±0.42 (1.9 to 3.7)	2.78±0.26 (2.2 to 3.2)	0.970
Axial length (mm)	24.38±1.60 (22.4 to 27.6)	24.98±1.73 (22.4 to 27.9)	0.187
WTW (mm)	11.72±0.37 (11.0 to 12.5)	11.77±0.35 (11.0 to 12.4)	0.838
Lens thickness (mm)	4.37±0.50 (3.6 to 5.3)	4.52±0.29 (4.0 to 5.1)	0.358
Flat keratometry (D)	43.12±1.43 (40.9 to 45.3)	42.58±1.36 (40.2 to 44.7)	0.729
Steep keratometry (D)	43.71±1.48 (41.2 to 46.1)	43.05±1.38 (41.3 to 45.3)	0.159
SA (μm)	0.16±0.08 (-0.1 to 0.4)	0.19±0.11 (0.1 to 0.4)	0.173
RMS HOA (μm)	0.34±0.10 (0.2 to 0.6)	0.38±0.13 (0.2 to 0.6)	0.118

[a]Pre-operative visual acuity was measured monocularly. *P*-values were calculated using Generalized estimating equations (GEE) to adjust for inter-eye correlation, except for gender (Chi-square test). UDVA: Uncorrected distance visual acuity; CDVA: Corrected distance visual acuity; logMAR: Logarithm of the minimum angle of resolution; ACD: Anterior chamber depth; WTW: White to white; D: Diopter; SA: Spherical aberration; RMS HOA: Root mean square higher-order aberrations.

an objective characterization of the lens itself in a controlled setting, allowing an ideal environment for direct comparisons between IOLs independent of each patient's anatomical or optical conditions. Thus, the optical quality of the GM and GMP was evaluated using an automated Optispheric IOL Pro 2 metrology platform (Trioptics GmbH, Germany)[20]. Measurements were performed with a model eye filled with balanced salt solution and equipped with a corneal lens simulating the average level of SA found in the population[21-22]. All measurements were conducted under polychromatic conditions and with a 3.5 mm aperture for the assessment of the modulation transfer function (MTF), through-focus MTF (TF-MTF), and simulated visual acuity (simVA) to predict the defocus curve from objective IOL measurements. The simVA was derived using the concept of the area under the MTF and non-linear fitting[23], allowing for calculation of the predicted VA at each defocus level based on objective optical-quality parameters. Two samples each of the GM and GMP IOLs were studied, all with a base power of 20.0 D.

Statistical Analysis To account for the inter-eye correlation arising from the inclusion of both eyes of some patients, generalized estimating equations (GEE) were used to compare all continuous variables (including preoperative parameters and postoperative visual outcomes) between the two groups. Categorical variables were analyzed using the Chi-square test. A post-hoc power analysis based on the primary outcome (intermediate VA at 66 cm) revealed an effect size (Cohen's *d*) of 0.91, achieving a statistical power of 89% with the current uneven sample size. All analyses were performed using Python (statsmodels library), and a *P*-value<0.05 was considered statistically significant.

RESULTS

Clinical Study A total of 48 patients (54 eyes) were included in the analysis, of which 30 patients (33 eyes) received the GM IOL and 18 patients (21 eyes) the GMP IOL. Table 1 shows the preoperative characteristics of the patients in both groups. The mean age was 59.6±6.1y (range: 48–72) in the GM group and 61.6±5.8y (range: 49–69) in the GMP group (*P*=0.339). There were no statistically significant differences in the mean preoperative UDVA [0.65±0.43 logMAR in the GM *vs* 0.60±0.35 logMAR in the GMP group, respectively (*P*=0.993)] and CDVA values [0.17±0.12 logMAR in the GM group *vs* 0.16±0.11 logMAR in the GMP group (*P*=0.809)] between the groups. Further baseline biometric and keratometric parameters as well as the SA and RMS HOA were also comparable between the groups (all *P*>0.05; Table 1).

Visual and refractive outcomes are shown in Table 2. At 3mo postoperatively, there was no statistically significant difference in the mean monocular UDVA between the two groups [0.05±0.05 logMAR in the GM *vs* 0.07±0.04 logMAR in the GMP group (*P*=0.078)]; however, the GM group demonstrated a statistically slightly superior CDVA (0.03±0.03 logMAR) than the GMP group (0.05±0.03 logMAR; *P*=0.003).

Intermediate vision at 66 cm was significantly better in the GM group (0.14±0.11 logMAR) compared with the GMP group (0.24±0.11 logMAR; *P*=0.033). Conversely, near vision at 33 cm was significantly better in the GMP (0.08±0.13 logMAR) compared to GM group (0.17±0.17 logMAR; *P*=0.048), while near vision at 40 cm was not statistically significantly different between the two groups [0.12±0.14 logMAR in the GM *vs* 0.11±0.11 logMAR in the GMP group (*P*=0.950)].

There were no statistically significant differences in the target

Table 2 Clinical results 3mo after surgery mean±SD (range)

Monocular visual outcome	Gemetric	Gemetric Plus	*P*
UDVA (logMAR)	0.05±0.05 (0 to 0.1)	0.07±0.04 (0 to 0.1)	0.078
CDVA (logMAR)	0.03±0.03 (0 to 0.1)	0.05±0.03 (0 to 0.1)	0.003
UIVA (logMAR) 66 cm	0.14±0.11 (0 to 0.4)	0.24±0.11 (0.1 to 0.4)	0.033
UNVA (logMAR) 40 cm	0.12±0.14 (0 to 0.4)	0.11±0.11 (0 to 0.2)	0.950
UNVA (logMAR) 33 cm	0.17±0.17 (0 to 0.5)	0.08±0.13 (0 to 0.4)	0.048
Target SE (D)	-0.11±0.21 (-0.5 to 0.3)	-0.03±0.14 (-0.2 to 0.2)	0.238
MRSE (D)	-0.32±0.43 (-1.3 to 0.5)	-0.24±0.40 (-1.3 to 0.3)	0.333
Refractive error (D)	0.21±0.36 (-0.5 to 1.1)	0.21±0.38 (-0.2 to 1.2)	0.264
Mean absolute error (D)	0.33±0.26 (0 to 1.1)	0.30±0.30 (0 to 1.2)	0.217

P-values were calculated using Generalized estimating equations (GEE) to adjust for inter-eye correlation, except for gender (Chi-square test). UDVA: Uncorrected distance visual acuity; CDVA: Corrected distance visual acuity; UIVA: Uncorrected intermediate visual acuity; UNVA: Uncorrected near visual acuity; logMAR: Logarithm of the minimum angle of resolution; SE: Spherical equivalent; MRSE: Manifest refraction spherical equivalent; D: Diopter.

SE (*P*=0.238) or the mean postoperative manifest refraction spherical equivalent (MRSE; *P*=0.333) between the two groups (Table 2). Similarly, the mean refractive PE (*P*=0.264) and the MAE (*P*=0.217) was comparable between both groups.

The mean monocular defocus curves are shown in Figure 1. Both IOLs showed comparable distance performance around 0. The GM curve showed slightly better VA at the intermediate defocus of approximately −1.5 D, whereas the GMP curve exhibited a modest improvement near −2.5 D, corresponding to near vision. These trends appear consistent with their respective light distribution profiles; however, statistical analysis using GEE revealed no statistically significant differences between the two groups at any specific defocus level (all *P*>0.05).

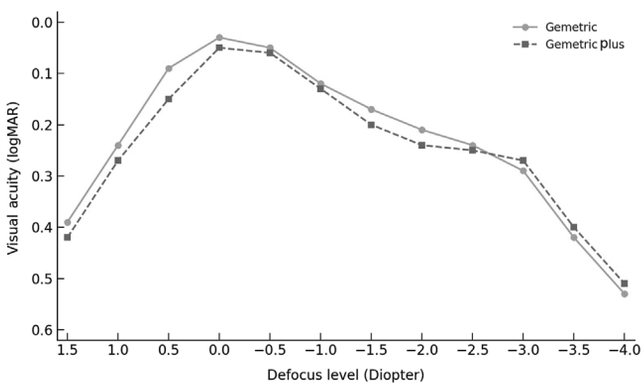

Figure 1 Monocular distance-corrected defocus curves with the Gemetric™ and Gemetric™ Plus intraocular lens logMAR: Logarithm of the minimal angle of resolution.

Optical Bench Testing The GM demonstrated higher MTF levels at the best-far focus, showing an MTF value of 0.21±0.00 at 50 cyc/mm compared to 0.15±0.00 for the GMP. The TF MTF presented in Figure 2A confirms the trifocal behavior of both IOLs, as indicated by the detection of the three main foci: far, intermediate, and near. This analysis also indicates the equivalence of the lenses in terms of the position of the secondary foci, while highlighting their differences in light distribution. The GM demonstrated improved far and intermediate MTF at 50 cyc/mm; however, the GMP provided a higher near-MTF peak. Figure 2B presents the laboratory predicted defocus curves of the two models. This analysis demonstrates a difference of 0.03 logMAR at 0 D in favor of the GM IOL. The difference in optically-simulated VA at -1.50 D (66 cm) and -2.5 D (40 cm) was 0.02 logMAR, with the GM showing minimally better VA at intermediate, while the GMP was slightly superior at near.

DISCUSSION

The present study compared the clinical outcomes of GM and GMP, two trifocal IOLs with different light distribution profiles. Both lenses demonstrated excellent distance VA and reliable refractive predictability at 3mo postoperatively, consistent with the performance reported for other modern trifocal IOLs.

A key finding of this study was the difference in intermediate and near vision between the two groups. GM achieved significantly better UIVA at 66 cm, whereas GMP provided superior near vision at 33 cm. VA at 40 cm was comparable between the two groups. These results are in alignment with their optical designs: GM allocates a relatively higher proportion of light to intermediate and distance foci, while GMP directs more light to the near focus. This demonstrates how differences in light distribution translate into clinically meaningful differences in functional vision.

From a clinical perspective, these complementary characteristics raise the possibility of contralateral implantation, where one eye receives GM and the fellow eye GMP, to achieve a broader range of spectacle independence. Such a mix-and-match approach has been applied to other multifocal IOLs

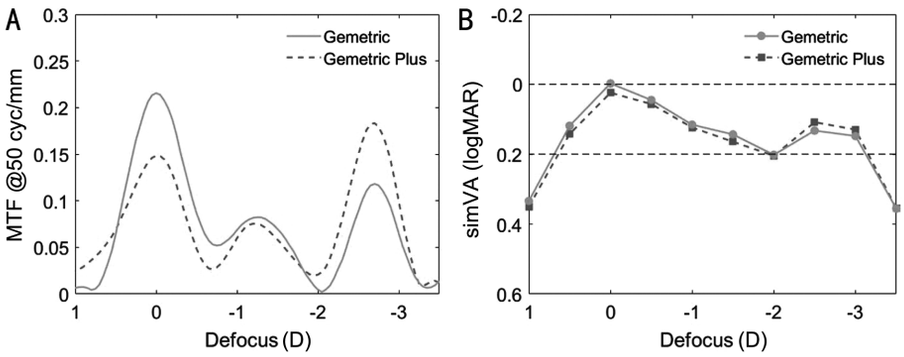

Figure 2 The through-focus modulation transfer function (MTF) at 50 cyc/mm (A) and simulated visual acuity (B) of the Gemetric™ and Gemetric™ Plus intraocular lenses SimVA: Simulated visual acuity; logMAR: Logarithm of the minimal angle of resolution.

and could represent a useful strategy for tailoring presbyopia correction[24-27].

To date, only a few studies reported clinical outcomes after implantation of these new-generation trifocal IOLs. Alió Del Barrio *et al*[28] assessed refractive results after paired implantation GM and GMP IOLs in dominant and non-dominant eyes, respectively, in patients undergoing cataract surgery or refractive lens exchange and observed excellent visual outcomes at all three distances, with binocular defocus curve demonstrating 0.2 logMAR or better VA from +0.5 to -3.5 D. Inter-ocular VA differences at 6-mo postoperatively showed statistically significantly superior corrected near visual acuity (CNVA) values among non-dominant eyes with GMP; eyes with GM, in contrast, demonstrated better UIVA and distance-corrected intermediate visual acuity (DCIVA) values than those with GMP, though not statistically significant. In another clinical study, Kaymak *et al*[15] compared the clinical performance of bilateral GM, bilateral GMP, and paired GM/GMP implantation in cataract patients and reported that bilateral GM and paired GM/GMP strategies achieved superior intermediate VA compared to bilateral GMP in their distance-corrected binocular defocus curve at 6mo postoperatively, whereas bilateral GMP IOLs provided better near performance compared to bilateral GM or paired GM/GMP. Our clinical and laboratory analyses are consistent with the previous reports and demonstrate the impact of variation in light distribution in trifocal IOLs of the same optical platform on the patients' visual performance. The strong agreement between the measured experimental defocus curve and the simVA further supports the validity of the optical-bench model in predicting actual visual outcomes for both IOLs (Figure 2).

Unlike the previous reports, however, our study presents real-world clinical data, showing IOL performance even under non-ideal conditions, such as mean preoperative RMS HOA of >0.3 μm in both groups. Nevertheless, despite such ocular imperfections, both GM and GMP IOLs demonstrated robust and comparable optical performance. Nonetheless, inclusion of such eyes with elevated optical aberrations may explain the slight differences in the visual outcomes observed herein and in the literature.

Interestingly, our monocular visual analysis demonstrated a minimally, yet statistically significantly superior postoperative CDVA in the bilateral GM compared to bilateral GMP group at 3mo postoperatively. Given the mean difference of merely 0.02 logMAR, however, this can be considered clinically negligible. However, Kaymak *et al*[15] also observed superior plano vision in the bilateral GM group compared to bilateral GMP or paired GM/GMP groups in their distance-corrected binocular defocus curve, suggesting a trend towards better CDVA when GM is implanted bilaterally.

One important aspect to consider in premium IOL surgery is the incidence of photic phenomena that may be bothersome to some patients despite excellent unaided vision across multiple distances and limit their satisfaction. With trifocal IOLs having been shown to generate more halo and glare effects than EDOF lenses[29], mix-and-match implantation is an alternative strategy that may mitigate the extent of dysphotopsia by implanting a different, usually non-trifocal lens into the contralateral eye[24-25,27]. Only one study thus far has reported subjective questionnaire results after implantation of these new-generation trifocal IOLs, and observed no statistically significant differences between bilateral GM, bilateral GMP, and mix-and-match GM/GMP groups for the frequency, severity, or degree of bother of photic phenomena at 6mo postoperatively[15]. Future studies with larger sample size evaluating the differences in rate of visual disturbances and patient satisfaction are necessary confirm the advantages and drawbacks of each implantation strategy using this new-generation trifocal lenses.

This study has several limitations. First, subjective visual quality parameters such as contrast sensitivity, dysphotopsia, patient satisfaction, and spectacle independence were not assessed. Second, the follow-up period was limited to 3mo, which does not allow assessment of long-term stability or late complications. Third, only monocular visual acuities were evaluated, without binocular outcomes that might better

reflect daily visual function. Lastly, the sample sizes of our groups were imbalanced; and while the statistical power for the primary outcome (UIVA) accounted for this uneven distribution, the near vision comparisons at 33 cm may still be underpowered. Future studies with longer follow-up, inclusion of subjective assessments, and binocular testing are necessary to confirm the stability of our outcomes and the long-term patient satisfaction.

In conclusion, our analysis of bilateral GM and GMP implantation provided excellent distance vision and refractive predictability, with distinct strengths reflecting their optical design: GM favored intermediate vision, whereas GMP demonstrated superior near vision. Further research is necessary to compare the visual quality outcomes of these lenses with regards to visual disturbances and patient satisfaction.

ACKNOWLEDGEMENTS

Authors' Contributions: Son HS and Koh K conceived and designed the study. Son HS, Yu SH, and Koh K collected and analyzed the clinical data. Auffarth GU and Łabuz G performed the optical bench testing and interpreted the experimental data. Son HS and Koh K drafted the manuscript. All authors reviewed, edited, and approved the final manuscript.

Data Availability Statement: The datasets generated and analyzed in this study are available from the corresponding author on reasonable request.

AI-Generated Content Disclosure: No artificial intelligence (AI)-assisted technologies were used in the generation, writing, or analysis of this manuscript.

Conflicts of Interest: Son HS, None; **Yu SH,** None; **Koh K,** None; **Auffarth GU** reports lecture fees and research grants from Hoya Corp., outside the submitted work; **Łabuz G,** None.

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