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ORIGINAL RESEARCH

# Visual Outcomes with Enhanced Monofocal and Non-Diffractive Extended Depth-of-Field Intraocular Lenses

Jakub Poliński[1,2], Dorota Walasik-Szemplińska[2], Joanna Sempińska-Szewczyk[1], Janusz Skrzypecki[3]

[1]Department of Ophthalmology, National Medical Institute of the Ministry of the Interior and Administration, Warsaw, Poland; [2]Sensor Cliniq, Warsaw, Poland; [3]Department of Experimental Physiology and Pathophysiology, Medical University of Warsaw, Warsaw, Poland

Correspondence: Janusz Skrzypecki, Department of Experimental Physiology and Pathophysiology, Medical University of Warsaw, Banacha 1B, Warsaw, 02-097, Poland, Tel +48 22 116 6195, Fax +48 22 57 20 734, Email jskrzypecki@wum.edu.pl



**Purpose:** To directly compare visual outcomes and quality of vision between an enhanced monofocal intraocular lens (IOL), a non-diffractive extended depth-of-field (EDOF) IOL, and a standard monofocal IOL.

**Methods:** This single-center, cohort study included patients undergoing bilateral cataract surgery targeted for emmetropia. Groups were stratified by implanted IOL: RayOne EMV (enhanced monofocal), AcrySof IQ Vivity (EDOF), and RayOne Aspheric (standard monofocal control). Outcomes included monocular and binocular visual acuities at distance, intermediate (66 cm), and near (40 cm), defocus curves, contrast sensitivity, and patient-reported outcomes (PRSIQ, QoV) assessed >3 months postoperatively.

**Results:** Corrected distance visual acuity was comparable across groups. The Vivity group demonstrated significantly better uncorrected and distance-corrected intermediate and near acuity compared to both EMV and monofocal groups ($p<0.001$). The EMV group showed significantly better intermediate acuity than the monofocal control ($p<0.05$) but no difference for near vision. The binocular functional depth of field (0.2 logMAR threshold) was 1.6 D for Vivity, 1.3 D for EMV, and 1.1 D for the monofocal control. Contrast sensitivity was significantly lower in the Vivity group compared to the EMV and monofocal groups ($p<0.05$). While Vivity achieved higher near-spectacle independence (31.8%), the EMV group reported significantly lower "bothersome" scores on the QoV questionnaire than both other groups.

**Conclusion:** The Vivity IOL provided the broadest range of vision, extending efficacy into near tasks, but was associated with reduced contrast sensitivity. The RayOne EMV IOL effectively bridged the gap between standard monofocal and EDOF technologies, significantly improving intermediate vision while maintaining a monofocal-like contrast sensitivity and safety profile.

**Keywords:** enhanced monofocal IOL, EDOF IOL, cataract, presbyopia

## Introduction

The paradigm of cataract surgery has shifted markedly in recent years, moving from simple visual restoration to a refractive procedure where patient expectations for complete spectacle independence are paramount.[1] While the bilateral implantation of standard monofocal intraocular lenses (IOLs) consistently yields high patient satisfaction for distance acuity, it inherently necessitates spectacle correction for intermediate and near tasks. This functional limitation drove the development of presbyopia-correcting optics.

Initially, multifocal IOLs addressed this gap, demonstrating significant improvements in intermediate and near visual acuity and high rates of spectacle independence.[2] However, the optical design of these lenses frequently necessitates a trade-off: the gain in focal range is often counterbalanced by reduced contrast sensitivity and the induction of photic phenomena, which remain a primary source of patient dissatisfaction.[3,4] Consequently, the industry has pivoted toward newer optical concepts, specifically Extended-Depth-of-Field (EDOF) and enhanced monofocal IOLs to bridge the gap between visual range and optical quality.

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EDOF technology represents a distinct optical category designed to create a continuous, elongated focal range rather than splitting light into distinct focal points.[5] These lenses utilize diverse optical mechanisms including diffraction, refraction, induction of spherical aberration, pinhole effects, or wavefront modulation to maintain excellent distance acuity while significantly improving intermediate vision.[6] According to the American Academy of Ophthalmology consensus, an IOL is classified as EDOF if it provides a depth of field at least 0.5 diopters greater than that of a monofocal control at a visual acuity threshold of 0.2 logMAR.[7] In clinical practice, the primary advantage of EDOF designs is their ability to offer functional spectacle independence for distance and intermediate tasks while maintaining a safety profile similar to monofocal lenses regarding glare and halos.

The most recent evolution in the IOL landscape is the "enhanced monofocal" category. These lenses employ refractive strategies, such as the induction of controlled spherical aberration, central zone refractive increases, or polynomial surface modifications, to elongate the depth of field.[8] Crucially, because enhanced monofocals generally avoid diffractive optics, they preserve monofocal-like image quality and minimize the risk of dysphotopsias.[9,10] This makes them an ideal solution for patients who desire improved functional intermediate vision but are contraindicated for multifocal or EDOF lenses. Clinical studies indicate that these lenses provide superior uncorrected intermediate vision and occasionally functional near vision compared to conventional monofocals, without compromising distance quality.[11–14]

Despite the expanding array of presbyopia-correcting options, there remains a paucity of literature providing direct, head-to-head comparisons between these distinct pseudo-accommodating technologies. Current evidence is largely derived from studies comparing individual premium lenses against standard monofocal controls, leaving a significant knowledge gap regarding the relative performance of EDOF designs versus enhanced monofocal IOLs in similar clinical populations. Therefore, the aim of this study is to fill this gap by directly comparing the visual outcomes and quality of vision between these lens modalities, to better inform surgical decision-making.

# Methods

## Study Design

This single-center retrospective cohort study was conducted at Sensor Cliniq (Warsaw, Poland). The study protocol was approved by the Bioethics Committee at the Regional Medical Chamber in Warsaw (approval No. KB/1520/2024) and adhered to the tenets of the Declaration of Helsinki. Written informed consent was obtained from all participants prior to enrollment.

The study included all eligible patients who consented to participate and who underwent bilateral cataract surgery with implantation of one of three intraocular lens models between 2021 and 2025. The same inclusion criteria were applied across all groups, including a minimum postoperative follow-up of 3 months. Patients were stratified into three groups:

Group 1 (Monofocal-plus): Implanted with RayOne EMV (Model RAO200E) or its toric equivalent (Rayner, UK).

Group 2 (EDOF): Implanted with AcrySof IQ Vivity (Model DFT015) or its toric equivalent (Alcon, USA).

Group 3 (Control): Implanted with a standard monofocal RayOne (Model RAO800C) (Rayner, UK).

Lens selection was determined based on individual patient preferences following comprehensive counseling regarding the optical capabilities and limitations of each design. Exclusion criteria included anterior or posterior segment pathologies compromising visual potential (eg., advanced glaucomatous optic neuropathy, diabetic retinopathy, severe dry eye syndrome, corneal dystrophies, pseudoexfoliation syndrome), a history of ocular trauma or prior surgery, and amblyopia with a predicted corrected distance visual acuity (CDVA) worse than 0.5 Snellen.

## Preoperative Assessment

Preoperative evaluation included the measurement of uncorrected and corrected distance visual acuity (UDVA/CDVA), manifest refraction, and intraocular pressure. Anterior and posterior segment was evaluated via slit-lamp biomicroscopy. Biometric parameters, including axial length, keratometry, and anterior chamber depth, were obtained using the IOLMaster 500 (Carl Zeiss Meditec AG, Germany). Corneal topography was assessed using the WaveLight Oculyzer II (Alcon, USA). IOL power calculations were performed using the Barrett Universal II formula, with plano targeted in both the dominant and non-dominant eyes in all groups, aiming to achieve a postoperative refraction as close to plano as

possible. The A-constants used for IOL power calculation were 119.2 for AcrySof IQ Vivity, 118.6 for RayOne EMV, and 118.6 for RayOne RAO800C.

## Surgical Technique

All surgeries were performed by four experienced surgeons under topical anesthesia using a standardized surgical technique, including a superior 2.2 mm clear corneal incision, phacoemulsification, and bimanual irrigation/aspiration with the Centurion Vision System (Alcon, USA). The postoperative regimen consisted of topical dexamethasone (four times daily), pranoprofen (three times daily), and levofloxacin (four times daily), tapered over a one-month period.

## Intraocular Lenses

Three optical designs were compared in this study:

RayOne EMV (Model RAO200E or its toric equivalent): A single-piece, hydrophilic acrylic, non-diffractive IOL (Group 1). Its aspheric optic is designed to induce controlled positive spherical aberration (up to 0.15μm across the 6-mm optic) to extend the focal range from distance to intermediate.

AcrySof IQ Vivity (Model DFT015 or its toric equivalent): A hydrophobic, non-diffractive EDOF IOL (Group 2). It features a biconvex optic with a central wavefront-shaping element (X-WAVE™ technology) that stretches and shifts the wavefront to enhance intermediate vision while utilizing negative spherical aberration.

RayOne Aspheric (Model RAO800C): A single-piece, hydrophobic acrylic monofocal IOL (Group 3). This lens features an aberration-neutral posterior aspheric surface and served as the control.

## Postoperative Assessment

Visual outcomes were assessed monocularly and binocularly under photopic conditions. Visual acuity was measured using Early Treatment Diabetic Retinopathy Study (ETDRS) charts (Good-Lite, USA) and recorded in logMAR at three distances: uncorrected distance visual acuity (UDVA) and corrected distance visual acuity (CDVA) at 4 m, uncorrected intermediate visual acuity (UIVA) and distance-corrected intermediate visual acuity (DCIVA) at 66 cm, and uncorrected near visual acuity (UNVA) and distance-corrected near visual acuity (DCNVA) at 40 cm. Defocus curves were evaluated monocularly and binocularly under photopic conditions using standard ETDRS charts at 4 m. Testing was performed over best-corrected distance refraction, ranging from +1.00 D to −2.50 D in 0.50 D increments, with randomized optotype presentation to prevent memorization. Contrast sensitivity was assessed using Pelli-Robson charts (Mars Perceptrix, USA) under photopic conditions and reported in logCS. Postoperative anatomic assessment included optical biometry (IOLMaster 500) and corneal tomography (WaveLight Oculyzer II). Patient-reported outcome measures (PROMs) were collected using the Quality of Vision (QoV) Questionnaire and the Patient-Reported Spectacle Independence Questionnaire (PRSIQ).

## Statistics

Statistical analysis was performed using Python (SciPy and Pandas libraries). Continuous variables are presented as mean ± standard deviation (SD) and range (min–max). Categorical variables are expressed as counts and percentages. The normality of data distribution was assessed using the Shapiro–Wilk test. Due to the non-normal distribution of visual acuity outcomes (logMAR) and ordinal questionnaire scores (QoV, PRSIQ), non-parametric tests were employed. Differences between the three groups (Vivity, EMV, Monofocal) were evaluated using the Kruskal–Wallis test. In cases of statistically significant differences, post-hoc pairwise comparisons were conducted using the Mann–Whitney *U*-test. Categorical data, such as spectacle independence rates, were compared using the Chi-square test ($\chi^2$). For defocus curves, data are presented as mean ± standard error of the mean (SEM) to illustrate the precision of the estimates. A p-value of less than 0.05 was considered statistically significant.

The sample size was calculated a priori to detect a minimum clinically important difference of 0.5 Diopters in the functional depth of field (at the 0.2 logMAR threshold) between any of the three IOL groups. To account for multiple pairwise comparisons across the three study arms (Vivity, EMV, and standard monofocal), a Bonferroni correction was

applied, setting the adjusted alpha level at 0.0167. Assuming an estimated pooled standard deviation of 0.40 D based on preliminary analysis, and a statistical power of 90%, a minimum of 16 eyes per group was required.

# Results

## Visual Outcomes

Baseline demographic and clinical characteristics are summarized in Table 1. Tables 2 and 3 summarize the monocular and binocular visual outcomes. No statistically significant differences in monocular and binocular CDVA were found among the three groups ($p>0.05$). Regarding monocular UDVA, the Vivity group showed significantly better monocular acuity compared to the EMV and monofocal groups ($p<0.05$); in contrast, no statistically significant differences were observed in binocular UDVA among the groups ($p=0.102$).

**Table 1** Baseline Demographic and Clinical Characteristics of the Study Population

| Parameter | Vivity (n=85 Patients) | EMV (n=42 Patients) | Monofocal (n=82 Patients) | P (Overall) | P (Viv vs EMV) | P (Viv vs Mono) | P (EMV vs Mono) |
|---|---|---|---|---|---|---|---|
| Female n (%) | 53 (62.4%) | 29 (69.0%) | 57 (69.5%) | 0.573 | — | — | — |
| Age (years) mean ± SD [Range] | 67.44 ± 9.78 [40.00; 85.00] | 72.62 ± 7.61 [49.00; 86.00] | 72.45 ± 6.63 [42.00; 81.00] | 0.0002* | 0.007* | 0.0005* | 1.000 |
| Axial Length (mm) mean ± SD [Range] | 23.68 ± 1.05 [21.82; 26.37] | 23.21 ± 0.72 [21.98; 24.88] | 23.13 ± 0.76 [21.68; 24.95] | 0.005* | 0.094 | 0.006* | 1.000 |
| IOL Power (D) Mean ± SD [Range] | 20.91 ± 3.20 [11.00; 26.00] | 21.40 ± 1.93 [16.50; 24.50] | 22.29 ± 1.79 [17.50; 29.00] | 0.022* | 1.000 | 0.053 | 0.062 |
| Preoperative BCVA (logMAR) Mean ± SD [Range] | 0.34 ± 0.24 [0.00; 1.30] | 0.52 ± 0.38 [0.22; 1.70] | 0.40 ± 0.23 [0.22; 1.70] | 0.002* | 0.009* | 0.010* | 0.879 |
| Postoperative SE (D) Mean ± SD [Range] | −0.20 ± 0.40 [−2.25; 0.50] | −0.22 ± 0.31 [−1.00; 0.62] | −0.17 ± 0.42 [−1.12; 1.00] | 0.514 | — | — | — |
| Postoperative Refractive Cylinder (D) Mean ± SD [Range] | −0.13 ± 0.31 [−1.50; 0.00] | −0.32 ± 0.52 [−1.25; 0.00] | −0.45 ± 0.56 [−2.00; 0.00] | <0.0001* | 0.005* | <0.0001* | 0.306 |

**Notes**: * p-values < 0.05 indicate statistical significance.
**Abbreviations**: BCVA, best corrected visual acuity; SE, spherical equivalent.

**Table 2** Postoperative Monocular Visual Outcomes in the First-Operated Eye for the Three Intraocular Lens Groups

| Visual Acuity (logMAR) | Vivity (mean ± SD) | EMV (mean ± SD) | Monofocal (mean ± SD) | P (Overall) | P (Viv vs EMV) | P (Viv vs Mono) | P (EMV vs Mono) |
|---|---|---|---|---|---|---|---|
| UDVA | 0.08 ± 0.14 | 0.11 ± 0.12 | 0.12 ± 0.14 | 0.039* | 0.045* | 0.025* | 0.824 |
| CDVA | 0.01 ± 0.07 | 0.02 ± 0.08 | 0.01 ± 0.07 | 0.742 | 0.866 | 0.450 | 0.738 |
| UIVA | 0.17 ± 0.10 | 0.25 ± 0.12 | 0.33 ± 0.23 | <0.001* | <0.001* | <0.001* | 0.021* |
| DCIVA | 0.20 ± 0.10 | 0.30 ± 0.11 | 0.34 ± 0.10 | <0.001* | <0.001* | <0.001* | 0.044* |
| UNVA | 0.41 ± 0.14 | 0.49 ± 0.16 | 0.52 ± 0.13 | <0.001* | 0,009* | <0.001* | 0.43 |
| DCNVA | 0.46 ± 0.12 | 0.54 ± 0.13 | 0.55 ± 0.10 | <0.001* | 0,001* | <0.001* | 0.563 |

**Note**: *p-values < 0.05 indicate statistical significance.
**Abbreviations**: UDVA, uncorrected distance visual acuity; CDVA, corrected distance visual acuity; UIVA, uncorrected intermediate visual acuity; DCIVA, distance corrected intermediate visual acuity; UNVA, uncorrected near visual acuity; DCNVA, distance corrected near visual acuity.

**Table 3** Postoperative Binocular Visual Outcomes for the Three Intraocular Lens Groups

| Visual Acuity (logMAR) | Vivity (mean ± SD) | EMV (mean ± SD) | Monofocal (mean ± SD) | P (Overall) | P (Viv vs EMV) | P (Viv vs Mono) | P (EMV vs Mono) |
|---|---|---|---|---|---|---|---|
| UDVA | 0.01 ± 0.08 | 0.04 ± 0.10 | 0.05 ± 0.14 | 0.102 | 0.069 | 0.075 | 0.873 |
| CDVA | −0.03 ± 0.05 | −0.02 ± 0.05 | −0.03 ± 0.06 | 0.734 | 0.446 | 0.968 | 0.505 |
| UIVA | 0.11 ± 0.08 | 0.20 ± 0.09 | 0.23 ± 0.10 | <0.001* | <0.001* | <0.001* | 0.081 |
| DCIVA | 0.13 ± 0.08 | 0.23 ± 0.08 | 0.27 ± 0.09 | <0.001* | <0.001* | <0.001* | 0.014* |
| UNVA | 0.32 ± 0.11 | 0.42 ± 0.13 | 0.44 ± 0.12 | <0.001* | <0.001* | <0.001* | 0.19 |
| DCNVA | 0.37 ± 0.10 | 0.46 ± 0.10 | 0.49 ± 0.10 | <0.001* | <0.001* | <0.001* | 0.081 |

**Note**: *p-values < 0.05 indicate statistical significance.
**Abbreviations**: UDVA, uncorrected distance visual acuity; CDVA, corrected distance visual acuity; UIVA, uncorrected intermediate visual acuity; DCIVA, distance corrected intermediate visual acuity; UNVA, uncorrected near visual acuity; DCNVA, distance corrected near visual acuity.

For intermediate vision, the Vivity group demonstrated significantly better monocular and binocular UIVA and DCIVA compared to both the EMV and monofocal groups ($p<0.001$). The EMV group showed significantly better monocular UIVA ($p=0.021$) and DCIVA ($p=0.044$) than the monofocal control. Binocularly, this superiority of EMV over monofocal was statistically significant for DCIVA ($p=0.014$) but did not reach significance for UIVA ($p=0.081$).

Regarding near vision (UNVA and DCNVA), the Vivity group achieved significantly better monocular and binocular outcomes compared to the other two groups ($p\leq0.009$). No significant differences were observed between the EMV and monofocal groups for near vision outcomes ($p>0.05$).

## Refractive Outcomes

Postoperative spherical equivalent was −0.19 ± 0.35 D in the Vivity group, −0.18 ± 0.37 D in the EMV group, and −0.20 ± 0.45 D in the monofocal group, with no statistically significant difference between groups. Postoperative refractive cylinder differed between groups, with mean values of −0.13 ± 0.31 D in the Vivity group, −0.32 ± 0.52 D in the EMV group, and −0.45 ± 0.56 D in the monofocal group. Pairwise analysis showed significant differences between Vivity and EMV ($p = 0.005$) and between Vivity and monofocal ($p < 0.0001$), whereas the difference between EMV and monofocal was not significant ($p = 0.306$). The distributions of postoperative visual acuity, the UDVA–CDVA difference, and refractive cylinder are shown in Figures 1–3.

## Defocus Curve

Figures 4 and 5 illustrate the monocular and binocular defocus curves, respectively. At 0.00 D, no significant differences were found in either monocular or binocular curves ($p>0.05$).

## Monocular Defocus Curve

In the defocus range from −1.00 D to −2.50 D, statistically significant differences were observed between all three groups ($p<0.05$), with Vivity demonstrating the highest visual acuity, followed by EMV, and then the monofocal group. At the −0.50 D vergence only Vivity was significantly superior to the monofocal group ($p<0.05$). In the hyperopic range, Vivity performed significantly better than other groups at +1.00 D but not at +0.5 D ($p<0.05$).

## Binocular Defocus Curve

The binocular curve followed a similar trend. From −1.00 D to −2.50 D, significant differences were maintained ($p<0.05$ for all pairs). However, at −0.50 D, both the Vivity ($p<0.05$) and EMV ($p<0.05$) groups demonstrated significantly better acuity than the monofocal control. Additionally, the EMV group differed significantly from other cohorts at +0.50 D ($p<0.05$).


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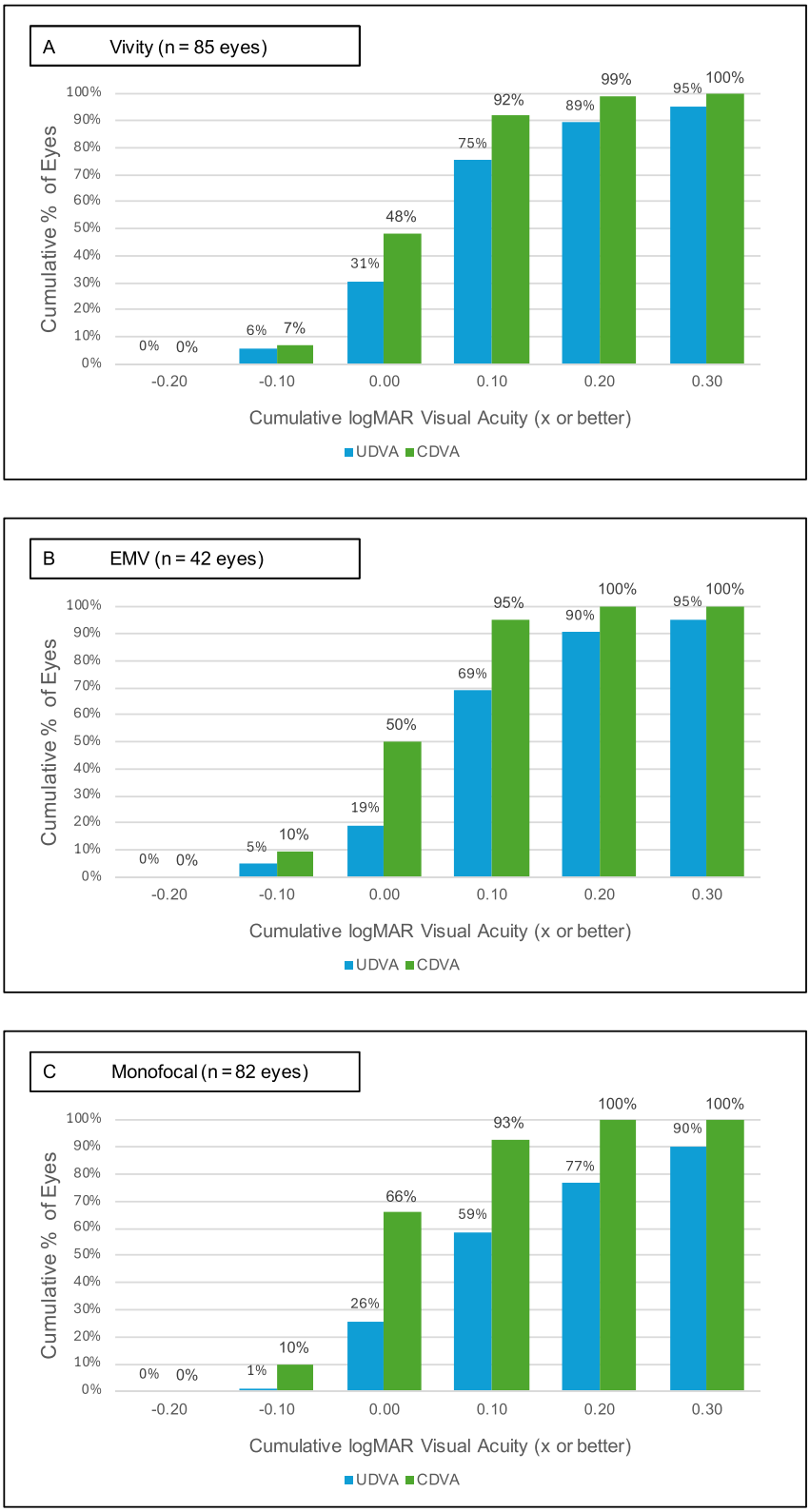
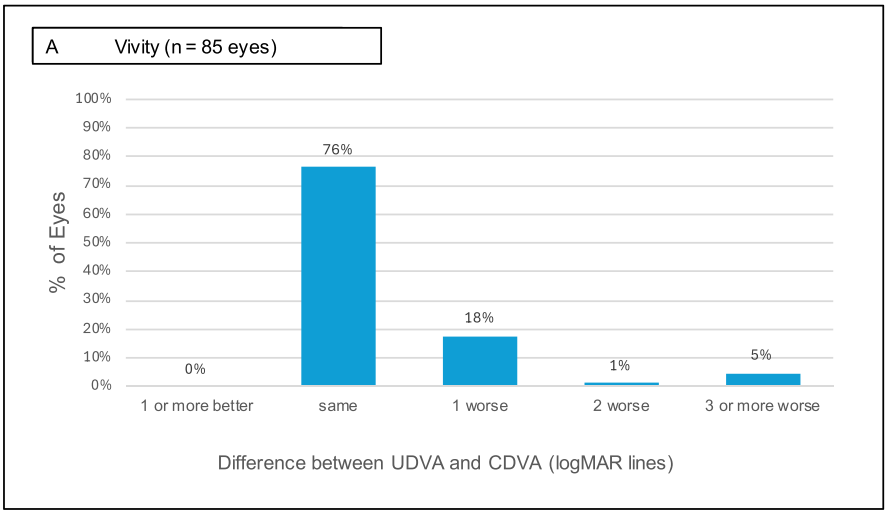
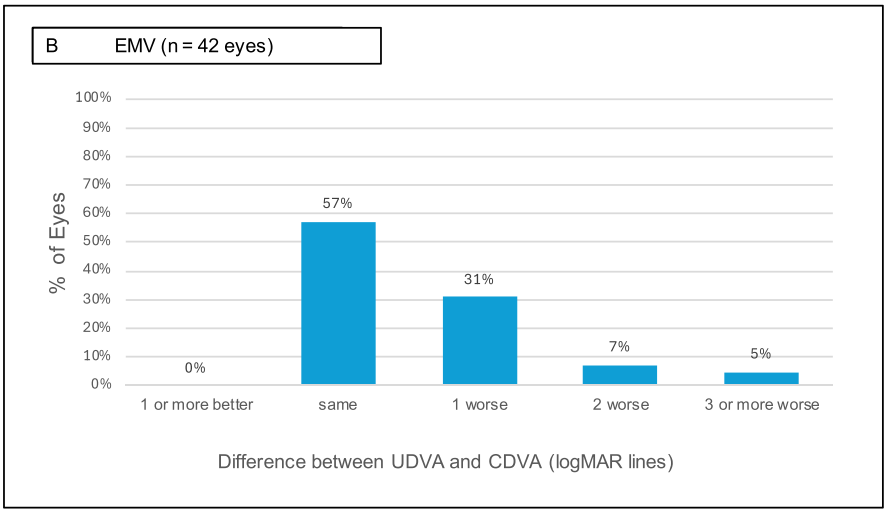



**Figure 1** Postoperative cumulative monocular uncorrected (UDVA) and corrected (CDVA) distance visual acuity in the first-operated eye for the three intraocular lens groups (**A**–**C**).



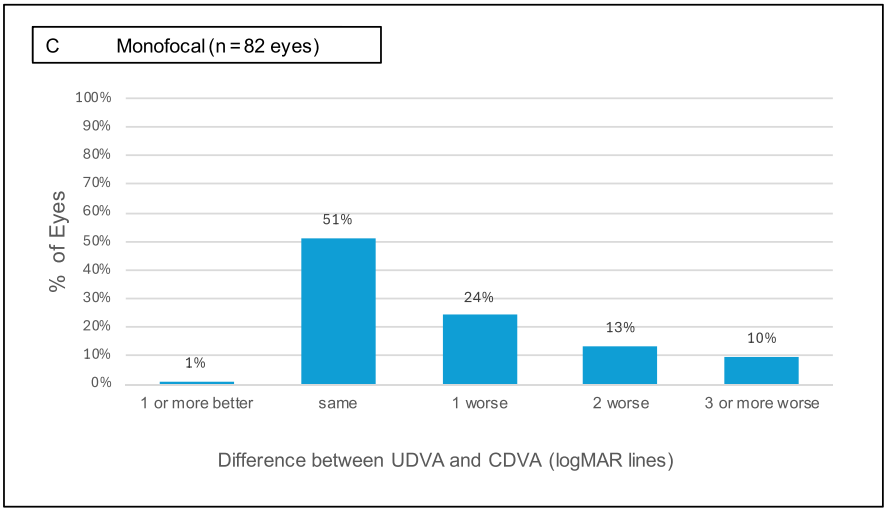




**Figure 2** Postoperative difference between uncorrected (UDVA) and corrected (CDVA) monocular distance visual acuity in the first-operated eye for the three intraocular lens groups (**A**–**C**).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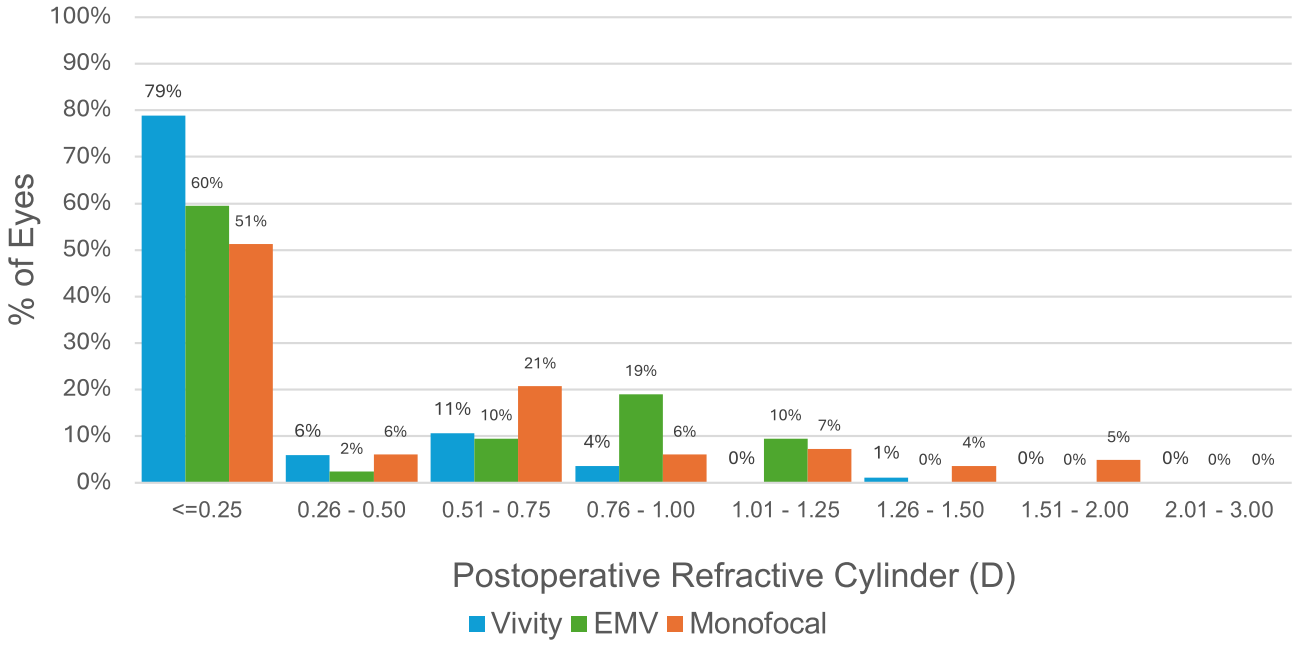


**Figure 3** Postoperative refractive cylinder distribution in the first-operated eye for the three intraocular lens groups.

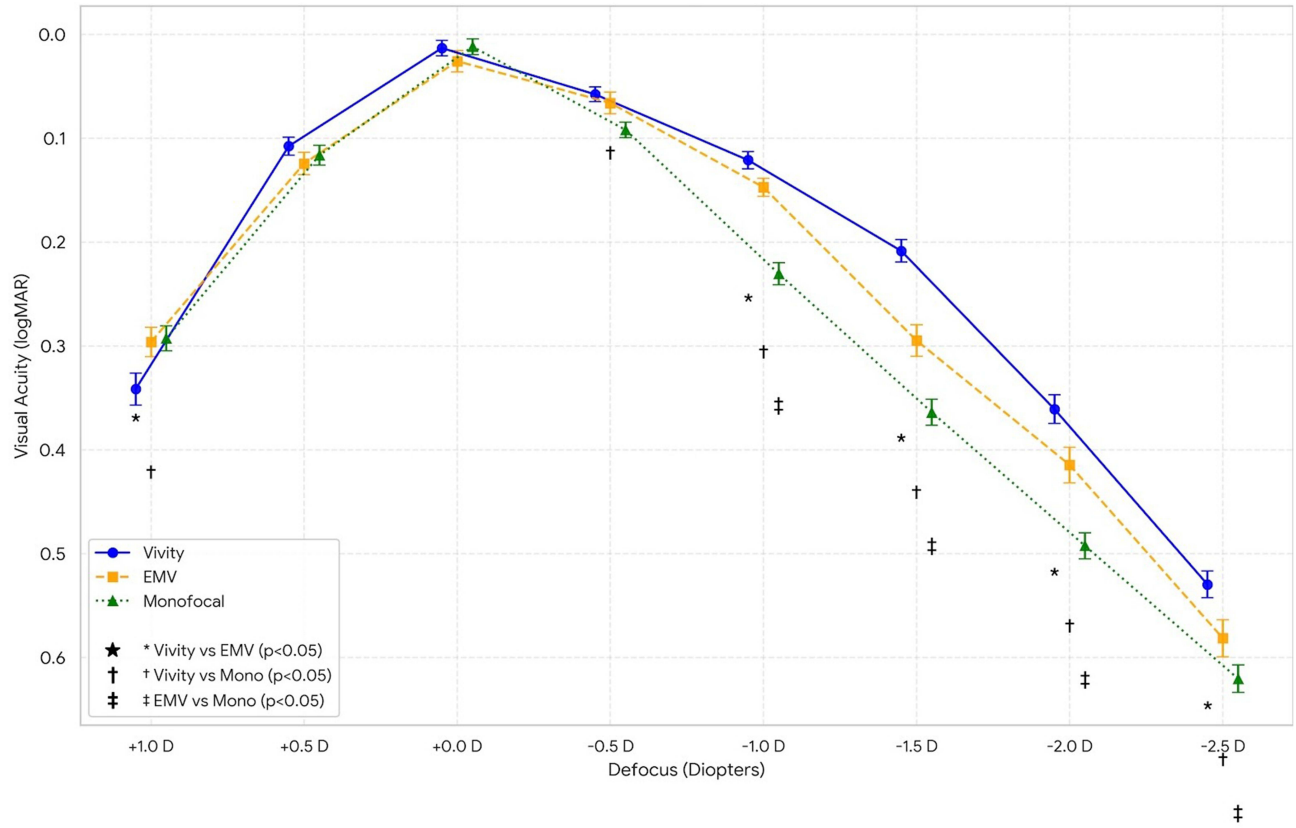


**Figure 4** Postoperative monocular defocus curve under photopic conditions with distance correction in the first-operated eye for the three intraocular lens groups.


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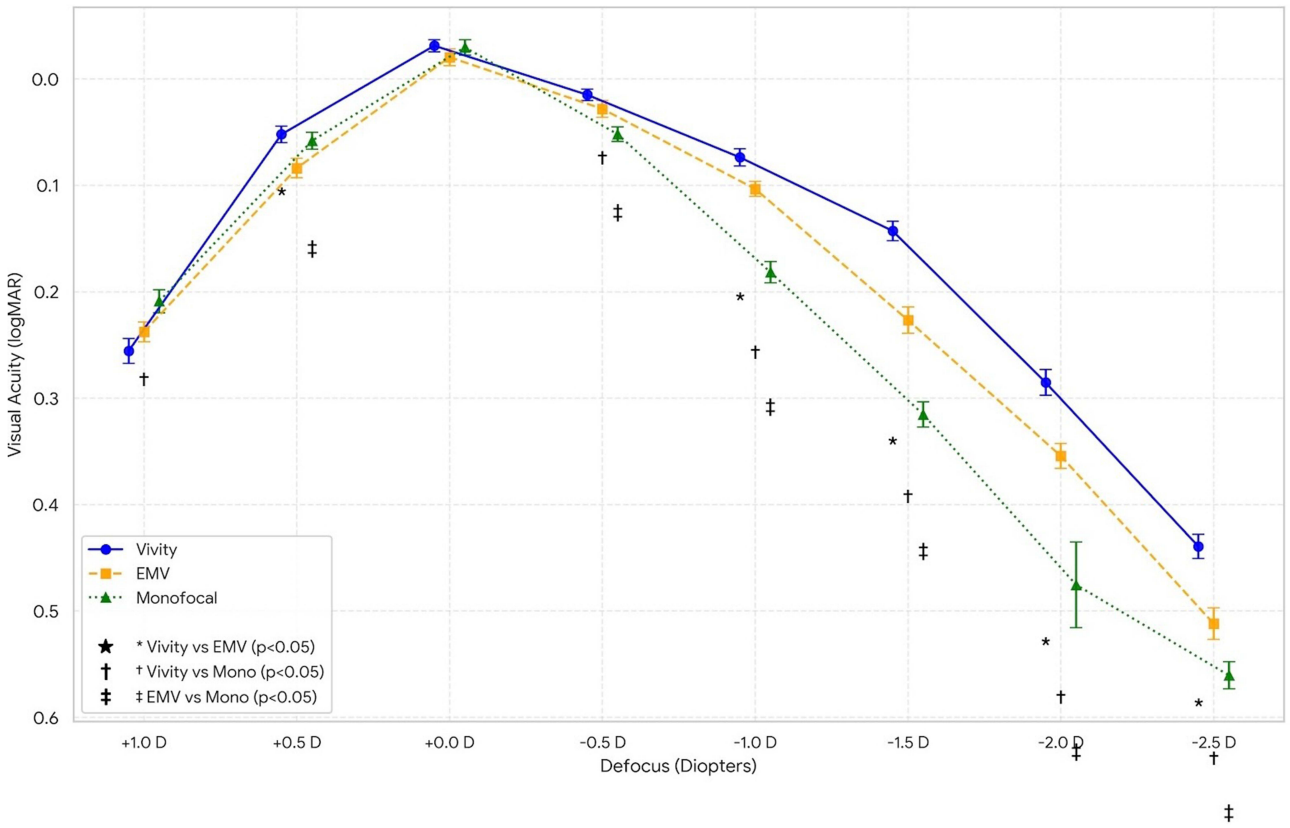


**Figure 5** Postoperative binocular defocus curve under photopic conditions with distance correction for the three intraocular lens groups.

## Contrast Sensitivity

Figure 6 presents the mean photopic contrast sensitivity (LogCS) values. The Vivity group exhibited significantly lower contrast sensitivity compared to both the EMV (p=0.004) and monofocal (p=0.001) groups. No statistically significant difference was observed between the EMV and monofocal groups (p=0.795).

## Pupil Size

Table 4 presents the postoperative pupil diameter measurements. The Vivity group exhibited significantly larger pupil sizes compared to the monofocal group in both IOL Master (p=0.036) and Pentacam (p=0.002) measurements. No statistically significant differences were observed between the EMV group and the other two groups (p>0.05).

## Spherical Aberration

Analysis of spherical aberration revealed no statistically significant differences in primary spherical aberration Z(4,0) (p=0.655) or secondary spherical aberration Z(6,0) (p=0.459) among the three groups.

## Patient Reported Spectacle Independence (PRSIQ)

Table 5 details the PRSIQ outcomes. Regarding complete spectacle independence rates, no significant differences were found for distance (p=0.051) or intermediate vision (p=0.13). However, for near vision, the Vivity group achieved a significantly higher rate of independence (31.8%) compared to the EMV (4.8%) and monofocal (6.1%) groups (p≤0.001).

In terms of frequency of spectacle wear, the Vivity group reported significantly less frequent usage than the monofocal group across all distances (p≤0.012). The EMV group showed significantly reduced frequency compared to the monofocal group only for near tasks (p=0.009).


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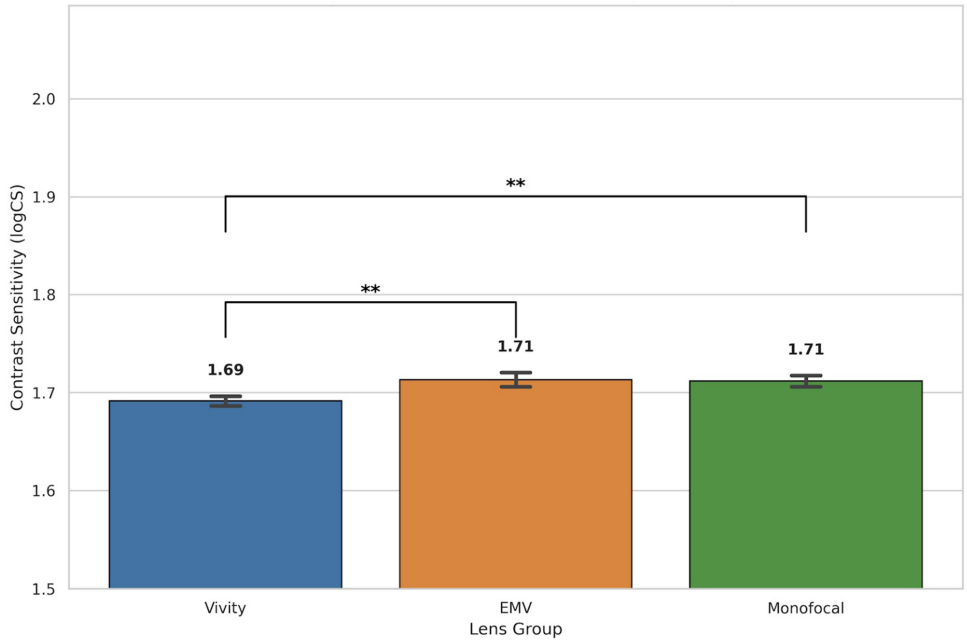


**Figure 6** Postoperative monocular photopic contrast sensitivity in the first-operated eye for the three intraocular lens groups. ** indicates a statistically significant difference for the indicated pairwise comparison (P < 0.05).

Regarding quality of vision, both Vivity and EMV groups scored significantly better than the monofocal group for distance and intermediate tasks (p<0.05), while Vivity was superior to both groups for near quality of vision (p<0.001).

## Quality of Vision (QoV) Questionnaire

Table 6 presents the QoV outcomes. Mean scores were uniformly low across all groups (range 0.12 to 0.69), with no statistically significant differences in frequency or severity subscales (p>0.05). However, regarding the bothersome subscale, the EMV group reported significantly lower scores compared to both the Vivity (p=0.034) and monofocal (p=0.004) groups.

**Table 4** Postoperative Pupil Size, Spherical Aberration, and Contrast Sensitivity in the First-Operated Eye for the Three Intraocular Lens Groups

| Parameter | Vivity (Mean ± SD) | EMV (Mean ± SD) | Monofocal (Mean ± SD) | P (Overall) | P (Viv vs EMV) | P (Viv vs Mono) | P (EMV vs Mono) |
|---|---|---|---|---|---|---|---|
| Pupil Size (IOL Master) [mm] | 3.70 ± 0.69 | 3.55 ± 0.71 | 3.47 ± 0.74 | 0.103 | 0.218 | 0.036* | 0.684 |
| Pupil Size (Pentacam) [mm] | 2.78 ± 0.54 | 2.60 ± 0.50 | 2.52 ± 0.53 | 0.005* | 0.092 | 0.002* | 0.206 |
| Aberrations Z (4,0) [µm] | 0.38 ± 0.07 | 0.38 ± 0.05 | 0.38 ± 0.07 | 0.655 | 0.42 | 0.459 | 0.912 |
| Aberrations Z (6,0) [µm] | 0.00 ± 0.01 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.459 | 0.998 | 0.294 | 0.284 |
| Contrast sensitivity (LogCS) | 1.69 ± 0.05 | 1.71 ± 0.05 | 1.72 ± 0.05 | <0.001* | 0.004* | 0.001* | 0.795 |

**Note**: * p-values < 0.05 indicate statistical significance.

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**Table 5** Patient-Reported Spectacle Independence Questionnaire (PRSIQ) Outcomes for the Three Intraocular Lens Groups

| Parameter | Vivity (n=85) | EMV (n=42) | Monofocal (n=82) | P (Overall) | P (Viv vs EMV) | P (Viv vs Mono) | P (EMV vs Mono) |
|---|---|---|---|---|---|---|---|
| **Spectacle Independence (% Yes)** | | | | | | | |
| Distance | 98.80% | 97.60% | 91.50% | 0.051 | 1 | 0.062 | 0.35 |
| Intermediate | 96.50% | 97.60% | 90.20% | 0.13 | 1 | 0.19 | 0.257 |
| Near | 31.80% | 4.80% | 6.10% | <0.001* | 0.001* | <0.001* | 1 |
| **Frequency of Spectacle Wear (Mean 1–5)^** | | | | | | | |
| Distance | 1.02 | 1.1 | 1.32 | 0.006* | 0.609 | 0.004* | 0.076 |
| Intermediate | 1.08 | 1.12 | 1.41 | 0.02* | 0.744 | 0.012* | 0.099 |
| Near | 2.69 | 3.62 | 4.21 | <0.001* | <0.001* | <0.001* | 0.009* |
| **Quality of Vision (Mean 1–5)^^** | | | | | | | |
| Distance | 4.95 | 4.93 | 4.72 | 0.01* | 0.754 | 0.012* | 0.04* |
| Intermediate | 4.89 | 4.93 | 4.65 | 0.006* | 0.403 | 0.014* | 0.015* |
| Near | 3.56 | 2.21 | 1.94 | <0.001* | <0.001* | <0.001* | 0.065 |
| **PRSIQ Total Score (Mean)^^^** | 13.12 | 15.76 | 17.76 | <0.001* | <0.001* | <0.001* | <0.001* |

**Notes**: * p-values < 0.05 indicate statistical significance. Spectacle Independence (% Yes): Percentage of patients reporting no need for glasses at a given distance; ^ Frequency of Spectacle Wear (1–5): 1 = "Never", 5 = "Always". Lower is better; ^^ Quality of Vision / Function (1–5): 5 = "Very Good", 1 = "Very Bad". Higher is better; ^^^ PRSIQ Total Score: Sum of all 9 items, adjusted so 1 is the best possible answer for each question. Range is 9 to 36. A score of 9 represents perfect, absolute spectacle independence at all distances. Lower is better.

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**Table 6** Quality of Vision (QoV) Questionnaire Outcomes for the Three Intraocular Lens Groups

| Scale (0–30 score) | Vivity | EMV | Monofocal | P (Overall) | P (Viv vs EMV) | P (Viv vs Mono) | P (EMV vs Mono) |
|---|---|---|---|---|---|---|---|
| Frequency | 0.69 | 0.43 | 0.61 | 0.241 | 0.103 | 0.311 | 0.437 |
| Severity | 0.66 | 0.4 | 0.56 | 0.182 | 0.068 | 0.381 | 0.257 |
| Bothersome | 0.39 | 0.12 | 0.51 | 0.016* | 0.034* | 0.284 | 0.004* |

**Note**:* p-values < 0.05 indicate statistical significance.

## Discussion

The results of this study demonstrate that both the extended depth-of-field (EDOF) and the enhanced monofocal IOLs maintained comparable corrected distance visual acuity and effectively extended the range of vision compared to the monofocal control. Nevertheless, the extent of this benefit differed between these two IOLs. The Vivity IOL provided the broadest range of vision, maintaining efficacy into the near range. In contrast, the EMV IOL effectively extended the depth of field for intermediate tasks, occupying the functional space between standard monofocal and EDOF technologies.

Our results align with data reported in prior studies regarding the Vivity IOL. In our study, Vivity monocular and binocular CDVA were comparable to those reported by Bala et al (−0.01 ± 0.01 and −0.06 ± 0.09).[15] Although our binocular distance-corrected intermediate and near acuities were slightly worse than those reported by Bala et al, the clinical advantage versus our monofocal control was clear. In our study, binocular DCIVA and DCNVA were better with Vivity by 0.14 logMAR (approximately 1.4 lines) and 0.12 logMAR (approximately 1.2 lines), respectively, compared with the monofocal IOL. This mirrors Bala et al, who observed a >1-line advantage for binocular DCIVA and an approximately 1-line advantage for binocular DCNVA in favor of Vivity over a monofocal control. Overall, this distribution of results aligns with the expected performance profile of the Vivity IOL.

In contrast to the broader range observed with Vivity, EMV results supported a more limited extension of depth of field. In our study, the EMV IOL binocular CDVA results were within the range reported by García et al (−0.07 ± 0.05) and Yeo et al (−0.01 ± 0.09).[16,17] Binocular DCIVA in our study (0.23 ± 0.08 logMAR) was likewise consistent with these reports (García et al 0.24 ± 0.09, Yeo et al 0.22 ± 0.13), while binocular DCNVA (0.46 ± 0.10 logMAR) was slightly lower than in the study by Yeo et al (0.38 ± 0.16). Our study adds a direct comparison with a monofocal control under an emmetropia-targeted setting. In this analysis, EMV showed a modest intermediate advantage over monofocal for binocular DCIVA (approximately 0.5 lines), whereas differences at near vision were small and not statistically significant. To our knowledge, data for EMV versus a monofocal control remain limited, and our results support an intermediate-focused benefit without a clear near advantage in this setting.

In our study, monocular CDVA was comparable between the Vivity group and the EMV group. The clinically meaningful separation emerged at intermediate and near, where Vivity provided an advantage of approximately 1 line for DCIVA and just under 1 line for DCNVA. This distribution is consistent with the expected performance profiles of these designs, with Vivity delivering a broader functional range extending toward near compared with the more intermediate-weighted enhancement of EMV. Our findings also align with Zeilinger et al[18] who reported superior monocular intermediate and near acuity with Vivity compared with EMV (DCIVA 0.15 vs 0.28 logMAR; DCNVA 0.30 vs 0.48 logMAR). However, it is worth noting that the EMV IOL is often intended be leveraged within a mini-monovision strategy rather than as a purely bilateral emmetropic solution. In that context, Zeilinger et al observed that Vivity's monocular advantage was largely attenuated when binocular visual acuities were assessed under mini-monovision (−0.50 D offset in the non-dominant eye), suggesting that a modest myopic target can elevate EMV functional performance to a comparable binocular range.

On the binocular distance-corrected defocus curve using the ≥0.2 logMAR criterion, the functional depth of field in our cohort was 1.6 D for Vivity, 1.3 D for EMV, and 1.1 D for the monofocal control. This corresponds to a 0.5 D extension for Vivity relative to the monofocal control and a 0.2 D extension for EMV relative to the monofocal control. Bala et al reported a broader functional depth of field for Vivity (approximately 2.0 D), yet the separation between Vivity and monofocal at the 0.2 logMAR threshold was 0.62 D, which is similar in magnitude to the benefit observed in our study.[15] Zeilinger et al similarly demonstrated a wider functional range for Vivity compared with EMV under binocular distance-corrected testing.[18]

A broader perspective may be gained by comparing these findings with results reported for other currently available EDOF platforms, particularly TECNIS Symfony (Johnson & Johnson Vision, USA) and Mini Well Ready (SIFI S.p.A, Italy). In the studies by Chang et al and Pedrotti et al, Symfony was evaluated against the monofocal IOL, and consistently provided better intermediate and near visual performance while maintaining distance vision comparable to that of the monofocal control.[19,20] Pedrotti reported binocular DCIVA and DCNVA values of 0.05 and 0.18 logMAR, respectively, compared with 0.30 and 0.46 logMAR in the monofocal group, while Chang reported DCIVA 0.03 vs 0.23 logMAR and DCNVA 0.23 vs 0.43 logMAR. Symfony was also associated with greater depth of field and higher spectacle independence, although this broader range of vision was accompanied by a higher incidence of photic phenomena, particularly halos and starbursts, whereas contrast sensitivity remained broadly comparable, with only slight reductions under selected mesopic glare conditions. Similar results have been reported for Mini Well Ready. In the comparative study by Pedrotti et al, using the aspheric monofocal IOL as a control, Mini Well provided better intermediate and near visual performance while preserving distance vision, with binocular DCIVA and DCNVA values of 0.02 and 0.11 logMAR, respectively, compared with 0.36 and 0.50 logMAR in the monofocal group.[21] Mini Well was also associated with better uncorrected intermediate and near visual acuity, faster reading speed, and more favorable patient-reported outcomes for near vision and spectacle dependence. At the same time, contrast sensitivity and objective optical quality were largely comparable to those of the monofocal lens, although objective halometry indicated a greater tendency toward halos. Taken together, these reports place the present Vivity findings within the broader pattern of EDOF-mediated extension of functional vision, while also indicating that the balance between visual range and photic phenomena may differ across specific EDOF designs.

A similar comparison can be made within the enhanced monofocal category, particularly with TECNIS Eyhance (Johnson & Johnson Vision, USA). In the studies by Auffarth et al and Giglio et al, Eyhance was evaluated against standard monofocal controls and consistently demonstrated better intermediate visual performance while maintaining distance vision comparable to that of conventional monofocal lenses.[12,22] Eyhance achieved binocular DCIVA values of 0.09 and 0.13 logMAR, respectively, compared with 0.20 and 0.29 logMAR in the corresponding monofocal control groups. Giglio et al also reported better binocular near vision with Eyhance (DCNVA 0.23 vs 0.33 logMAR). Defocus analysis likewise supported a greater depth of field than with standard monofocal designs. At the same time, the quality-of-vision profile remained largely comparable to that of monofocal controls, with no significant differences in contrast sensitivity or in the frequency of halos, glare, and starbursts, and with noninferior corrected distance visual acuity. Against this background, the present EMV findings support the concept of enhanced monofocal extension of functional vision beyond that of a standard monofocal IOL, while suggesting that the degree of intermediate and near benefit may vary across individual lens designs.

In our study, mean postoperative pupil size differed modestly between groups. The Vivity group had slightly larger pupils than the monofocal control, whereas the difference between Vivity and EMV was not statistically significant. One possible explanation is the younger age of the Vivity cohort relative to the EMV and monofocal groups, as pupil diameter is known to decrease with advancing age. Because neither age nor preoperative pupil size was used as a criterion for IOL selection, this imbalance most likely reflects the retrospective, non-randomized design and relatively small cohort sizes rather than intentional allocation. This finding is clinically relevant because prior studies suggest that outcomes with the Vivity IOL may be influenced by pupil size. Smaller pupils may improve near vision through a pinhole effect that may complement the lens's wavefront-stretching design, while larger pupils have been associated with more glare and halos and worse quality-of-vision scores.[23–25] For the EMV IOL, optical bench studies also suggest a pupil-size effect on performance, with better performance in smaller pupils.[26,27] In this context, the slightly larger pupil size in our Vivity group would be expected to attenuate, rather than exaggerate, near performance, which supports the interpretation that the observed intermediate and near advantage of Vivity over EMV is unlikely to be driven by a favorable pupil profile. Nevertheless, given the retrospective design, residual confounding and sampling variability cannot be excluded.

Spectacle independence for distance was high in all groups in our study. For intermediate spectacle independence, we found no significant differences between groups. This may reflect variability in patients' interpretation of intermediate vision and the possibility that many patients in our population infrequently perform tasks at true intermediate distances (eg., prolonged computer work or frequent dashboard viewing), which may limit their ability to detect differences

through questionnaire responses. In contrast, near spectacle independence differed markedly. Vivity achieved higher near independence (31.8%) than both EMV (4.8%) and monofocal (6.1%), while EMV and monofocal performed similarly. Our Vivity findings are consistent with prior reports in bilaterally targeted to emmetropia cohorts, as Bala et al[15] reported spectacle independence of 91.5% for distance, 75.5% for intermediate, and 29.2% for near. Comparable published data on spectacle independence after EMV implantation targeted to bilateral emmetropia remain limited.

In photopic conditions without glare, contrast sensitivity was slightly lower with Vivity than with both EMV and the monofocal IOL, while EMV and monofocal did not differ. However, the absolute between-group difference was only 0.03 log units (1.68 vs 1.71), which is smaller than a single letter step on the Pelli–Robson chart and is therefore unlikely to be clinically meaningful. In our study, QoV scores did not differ significantly between the three groups for frequency and severity, and bothersome scores were lower in the EMV group, indicating that small objective differences in photopic contrast sensitivity were not accompanied by clinically meaningful differences in patient-reported visual symptoms. Prior Vivity studies have similarly reported modest reductions in contrast sensitivity compared with monofocal IOLs, with the largest differences observed under more demanding conditions such as mesopic testing and higher spatial frequencies.[15] For EMV, studies generally support a monofocal-like image quality profile.[27] In a direct comparison, Zeilinger et al evaluated EMV versus Vivity and reported smaller halo size with EMV, but this did not translate into significant differences in perceived contrast sensitivity or patient-reported quality-of-vision questionnaire outcomes between the two lenses in their study.[18]

## Conclusions

In conclusion, our findings highlight that while both enhanced monofocal and non-diffractive EDOF designs effectively overcome the limitations of standard monofocal IOLs, they occupy distinct clinical niches. The Vivity IOL offers the broadest continuous range of vision, making it a superior choice for patients prioritizing near spectacle independence, provided they accept a minor, subclinical reduction in contrast sensitivity. Conversely, the RayOne EMV serves as an optimal solution for patients seeking improved intermediate functionality without compromising the optical quality and favorable dysphotopsia profile of a standard monofocal lens. These distinctions underscore the importance of personalized preoperative counseling to align the specific optical technology with the patient's individual visual requirements and tolerance for optical trade-offs.

## Disclosure

The authors report no conflicts of interest in this work.

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