

Short-Term Visual and Optical Performance of the ZEISS CT LUCIA 621P Intraocular Lens Across Different Power Ranges

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Purpose: To evaluate the short-term efficacy and optical performance of the ZEISS CT LUCIA 621P intraocular lens (IOL) in cataract patients using a diopter (D)-stratified approach.

Patients and Methods: This retrospective study included 304 eyes of 216 patients who underwent phacoemulsification with CT LUCIA 621P implantation. Eyes were stratified into four groups by implanted IOL power: Group 1 (<20.0 D, n=49), Group 2 (20.0–21.5 D, n=137), Group 3 (22.0–23.5 D, n=60), and Group 4 (≥24.0 D, n=58). Primary outcomes were monocular and binocular photopic/mesopic defocus curves and internal higher-order aberrations (HOAs) at 1 and 3 months because these directly evaluate the optical quality and depth of focus delivered by the non-constant aspheric ZEISS Optic design—the core innovative feature of the CT LUCIA 621P IOL—across the full spectrum of implanted powers. Secondary outcomes provide complementary clinical efficacy data; uncorrected and corrected distance visual acuity (UDVA/CDVA), uncorrected intermediate (UIVA) and near (UNVA), refractive predictability, and contrast sensitivity (CS). Analyses used generalized estimating equations (GEE) with an exchangeable correlation structure.

Results: All groups achieved excellent refractive predictability with convergence of spherical equivalent (SE) toward emmetropia ($p=0.398$). Mean monocular UDVA at 3 months was comparable across groups ($p=0.498$). Monocular and binocular UIVA and UNVA were also comparable (all $p>0.23$). Photopic and mesopic defocus curves showed similar depth of focus across groups ($p>0.05$ at most levels). Postoperative spherical aberration (SA) and coma remained low with no significant inter-group differences after generalized GEE adjustment ($p>0.17$). Photopic CS was comparable across IOL power groups at most spatial frequencies.

Conclusion: The CT LUCIA 621P IOL demonstrated consistent refractive predictability, VA across distances, and optical quality across a wide range of implanted powers, supporting its reliable use in contemporary cataract surgery.

Keywords: CT LUCIA 621P, non-constant aspheric IOL, ZEISS optic, diopter-stratified analysis, visual performance, optical quality, cataract surgery

Introduction

Cataract surgery with intraocular lens (IOL) implantation remains the most frequently performed ophthalmic procedure worldwide.¹ Although modern monofocal IOLs provide excellent distance visual acuity (VA), conventional fixed-aspheric designs exhibit power-dependent optical behavior that can compromise contrast sensitivity (CS) and defocus tolerance, particularly in high-power implants.²

Higher IOL powers (typically ≥24.0 diopters [D]) are associated with increased lens thickness and steeper curvature, leading to greater induction of spherical aberration (SA) and higher susceptibility to coma upon tilt or decentration—phenomena that are more pronounced in short axial length (AL) eyes.³ In contrast, low-power IOLs (<20.0 D) often implanted in long eyes may over-correct corneal SA. Traditional fixed-aspheric IOLs with a constant negative SA profile cannot adequately address these power-specific variations.⁴

To overcome these limitations, Carl Zeiss Meditec developed the patented non-constant aspheric ZEISS Optic Asphericity Concept, which is incorporated in the CT LUCIA 621P IOL (Carl Zeiss Meditec AG, Jena, Germany). This is a hydrophobic, monofocal, C-loop IOL featuring mild negative SA in the central 3.5–4.0 mm zone that gradually transitions to zero or slightly positive SA toward the periphery.^{5,6} The gradient profile is intended to optimize high-frequency CS under photopic conditions while enhancing tolerance to misalignment and maintaining performance under mesopic pupil dilation.⁷

Previous clinical studies have demonstrated good refractive predictability and visual outcomes with the CT LUCIA 621P.^{8–10} However, most reports analyzed the lens as a single cohort (mean power ~21–22 D) or performed head-to-head comparisons without power-stratified subgroup analysis.^{8,9} High-power subgroups (≥ 24.0 D) were either excluded or underpowered for separate evaluation.¹⁰ Consequently, whether the non-constant aspheric design truly mitigates power-dependent aberrations across the full clinical spectrum remains unproven.

The present retrospective, IOL power-stratified study was therefore conducted to evaluate the short-term (1–3 months) refractive, visual, and optical performance of the CT LUCIA 621P IOL across four power groups (<20.0 D to ≥ 24.0 D), while controlling for key biometric confounders (AL and pupil size). By providing subgroup-specific evidence, this analysis aims to support evidence-based, personalized IOL selection in modern cataract surgery.

Materials and Methods

Ethics Approval and Consent to Participate

This retrospective study was conducted in strict accordance with the ethical principles of the Declaration of Helsinki. The research protocol received approval from Public Institutional Bioethics Committee designated by the Korea Ministry of Health and Welfare (P01-202601-01-025), an independent nationally accredited central IRB under the Bioethics and Safety Act. This central IRB is authorized for clinical research at institutions without an internal review board. Patient data confidentiality was strictly maintained by anonymizing all personal identifiers prior to data extraction and analysis. Informed consent was waived by the IRB due to the retrospective design involving only anonymized data review without direct patient interaction (deliberation exemption).

Study Design

This retrospective, single-center, power-stratified observational study included 304 eyes of 216 patients who underwent uneventful phacoemulsification with implantation of the ZEISS CT LUCIA 621P IOL between August 2023 and October 2025 at Fatima Eye Clinic (Changwon, Republic of Korea).

Inclusion criteria were age ≥ 50 years, visually significant cataract, and preoperative corneal astigmatism ≤ 1.50 D (measured by IOLMaster 700 biometry [Carl Zeiss Meditec AG, Jena, Germany]). Exclusion criteria were previous ocular surgery, corneal pathology (eg, keratoconus, dystrophy), macular disease, glaucoma, diabetic retinopathy, or any intraoperative complication.

Eyes were stratified into four groups according to implanted IOL power: Group 1 (<20.0 D, $n=49$ eyes/33 patients), Group 2 (20.0–21.5 D, $n=137$ eyes/98 patients), Group 3 (22.0–23.5 D, $n=60$ eyes/46 patients), and Group 4 (≥ 24.0 D, $n=58$ eyes/39 patients). IOL power was calculated using the Barrett Universal II formula with IOLMaster 700.

Surgical Technique

All surgeries were performed by the same experienced surgeon (JJ) at Fatima Eye Clinic using a standardized technique as previously described.⁸ Briefly, procedures were conducted under topical anesthesia with the Centurion Vision System (Alcon Laboratories, Inc, Fort Worth, TX, USA). A 2.2-mm temporal clear corneal incision was created, followed by a continuous curvilinear capsulorhexis of approximately 5.0 mm. Phacoemulsification and cortical cleanup were completed with standard settings. The CT LUCIA 621P IOL was implanted into the capsular bag using the preloaded injector system. Postoperative regimen consisted of topical antibiotics (0.5% moxifloxacin) and steroids (1% prednisolone acetate), both tapered over 4 weeks, plus a non-steroidal anti-inflammatory agent (0.1% nepafenac sodium) as needed.

Postoperative Examinations

All measurements were performed at 1 month and 3 months postoperatively (mesopic defocus and CS at 1 month only). Objective refraction (sphere [SPH], cylinder [CYL], spherical equivalent [SE]) and pupil size were measured with the KR-800 auto kerato-refractometer (Topcon Corp, Tokyo, Japan). Monocular and binocular uncorrected distance VA (UDVA), uncorrected intermediate VA (UIVA at 80 cm and 66 cm), uncorrected near VA (UNVA at 40 cm), and corrected distance VA (CDVA) were assessed using Early Treatment Diabetic Retinopathy Study (ETDRS) charts under photopic conditions (85–100 cd/m²) and expressed as logarithm of the minimum angle of resolution (logMAR). Cumulative Snellen proportions were also recorded. Monocular and binocular distance-corrected defocus curves were measured from +1.0 D to −3.5 D in 0.5 D increments using an ETDRS chart at 4 m. Photopic testing (100 cd/m²) was performed at 1 and 3 months; mesopic testing (3 cd/m²) at 1 month.

Wavefront aberrations were measured with the OPD-Scan III (Nidek Co, Ltd, Gamagori, Japan) at a standardized 4-mm pupil diameter at 1 and 3 months postoperatively. Higher-order aberrations (HOAs) were quantified as root-mean-square (RMS, μm) values for SA and horizontal/vertical coma (coma H/V).

hopic CS was evaluated monocularly and binocularly at 1.5, 3, 6, 12, and 18 cycles per degree (cpd) at 1 month only (CSV-1000E, VectorVision, Greenville, OH, USA). The 3 month CS measurement could not be completed due to technical issues.

Statistical Analysis

Data were analyzed using R software (version 4.4.1; R Foundation for Statistical Computing, Vienna, Austria). Generalized estimating equations (GEE) models with an exchangeable correlation structure were employed to account for all inter-group comparisons of eye-level data to account for within-subject correlation between fellow eyes. For continuous outcomes (VA, refractive power, HOAs), GEE with Gaussian distribution and identity link function was used. Partial correlations were calculated to evaluate the relationships between pupil size and key visual and optical outcomes (SA, coma, UDVA, and CS), controlling for age and gender.

A priori sample size calculation was performed using G*Power software (version 3.1) based on the primary outcome of monocular CS at 1 month. Using one-way ANOVA with four power-stratified groups, a two-sided test, significance level of 0.05, statistical power of 80%, and effect size derived from pilot study data (group means: 1.34, 1.35, 1.23, and 1.32; within-group standard deviation: 0.2), the minimum required sample size was calculated as 244 eyes (122 patients), after accounting for a 10% dropout rate. The actual study enrolled 304 eyes from 216 patients, which exceeded the minimum required sample size and thereby confirmed adequate statistical power for the primary analysis. A *p*-value < 0.05 was considered statistically significant.

Results

Patient Demographics

Baseline characteristics are summarized in [Table 1](#). A total of 216 patients (304 eyes) underwent ZEISS CT LUCIA 621P IOL implantation and were stratified by implanted IOL power into four groups: Group 1 (<20.0 D; 49 eyes/33 patients), Group 2 (20.0–21.5 D; 137 eyes/98 patients), Group 3 (22.0–23.5 D; 60 eyes/46 patients), and Group 4 ($\geq$ 24.0 D; 58 eyes/39 patients). Mean age was comparable across groups (*p*=0.464). Gender distribution differed significantly (*p*<0.001), with male predominance in the low-power groups. AL decreased progressively with increasing IOL power (25.42 $\pm$ 1.41 mm in Group 1 vs 22.97 $\pm$ 0.62 mm in Group 4; *p*<0.001). Consistent with this biometric pattern, preoperative SE, SPH, CYL, and UDVA also showed significant inter-group differences (all *p*<0.001), whereas CDVA remained similar with no statistically significant inter-group difference (*p*=0.183). Pupil size differed significantly (*p*=0.0476), being smallest in the highest-power Group 4.

Refractive Predictability

Postoperative refractive outcomes are summarized in [Table 2](#). All four IOL power groups demonstrated excellent refractive predictability, with SE converging toward emmetropia at 3 months (range: −0.83 $\pm$ 0.81 D in Group 1 to –

Table 1 Baseline Demographics and Preoperative Ocular Characteristics Stratified by IOL Power Groups

Parameter	LUCIA621P Groups				Inter-Group p-value
	Group 1 (<20.0 D)	Group 2 (20.0–21.5 D)	Group 3 (22.0–23.5 D)	Group 4 (≥24.0 D)	
Age (years)	68.27±6.54	68.07±7.88	70.09±7.84	69.13±6.68	0.4640
Gender ratio (M:F)	26:7	59:39	18:28	13:26	<0.0001
Patients (N)	33	98	46	39	
Eyes (N)	49	137	60	58	
AL (mm)	25.42±1.41	23.92±1.11	23.37±0.59	22.97±0.62	<0.0001
Pupil size (mm)	4.66±0.68	4.58±0.82	4.74±0.94	4.25±0.71	0.0476
SPH (D)	−2.26±3.26	0.11±1.55	0.68±1.27	1.15±1.31	<0.0001
SE (D)	−2.74±3.36	−0.16±1.61	0.38±1.24	0.88±1.35	<0.0001
CYL (D)	−0.96±0.64	−0.54±0.62	−0.62±0.62	−0.54±0.59	0.0171
UDVA (logMAR)	0.76±0.48	0.51±0.37	0.41±0.26	0.41±0.36	0.0059
CDVA (logMAR)	0.29±0.23	0.3±0.35	0.21±0.2	0.22±0.36	0.1831

Notes: Inter-group p-values were calculated using generalized estimating equations (GEE) with an exchangeable correlation structure to account for within-subject correlation between fellow eyes (304 eyes from 216 patients). Data are presented as mean ± standard deviation (SD).

Abbreviations: IOL, intraocular lens; D, diopters; N, numbers; AL, axial length; SPH, spherical power; SE, spherical equivalent; CYL, cylindrical power; UDVA/CDVA, uncorrected/corrected distance visual acuity; logMAR, logarithm of the minimum angle of resolution.

Table 2 Preoperative and Postoperative Refractive Outcomes at 1 and 3 Months After Surgery Stratified by IOL Power Groups

Parameter		N	LUCIA621P Groups				Inter-group p-value
			Group 1 (<20.0 D)	Group 2 (20.0–21.5 D)	Group 3 (22.0–23.5 D)	Group 4 (≥24.0 D)	
SPH (D)	Pre	304	−2.26±3.26	0.11±1.55	0.68±1.27	1.15±1.31	<0.0001
	1M	269	−0.77±0.94	−0.28±0.74	−0.23±0.72	−0.37±0.84	0.1148
	3M	208	−0.64±0.79	−0.30±0.73	−0.37±0.80	−0.21±0.64	0.2442
SE (D)	Pre	304	−2.74±3.36	−0.16±1.61	0.38±1.24	0.88±1.35	<0.0001
	1M	269	−0.95±0.91	−0.46±0.76	−0.40±0.70	−0.65±0.90	0.0654
	3M	208	−0.83±0.81	−0.50±0.76	−0.53±0.76	−0.48±0.68	0.3982
CYL (D)	Pre	304	−0.96±0.64	−0.54±0.62	−0.62±0.62	−0.54±0.59	0.0171
	1M	268	−0.36±0.42	−0.36±0.42	−0.33±0.45	−0.56±0.55	0.2907
	3M	207	−0.38±0.44	−0.41±0.45	−0.34±0.36	−0.53±0.52	0.4990

Notes: Inter-group p-values were calculated using generalized estimating equations (GEE) with an exchangeable correlation structure to account for within-subject correlation between fellow eyes. Data are presented as mean ± standard deviation (SD).

Abbreviations: SPH, spherical power; SE, spherical equivalent; CYL, cylinder power; D, diopters; pre, preoperative; 1M/3M, 1 month/3 months postoperatively; N, numbers of eyes.

0.48±0.68 D in Group 4; $p=0.398$). No significant inter-group differences were observed. Complete sphere and cylinder data are provided in Table 2 for reference.

VA Outcomes

Postoperative VA results are summarized in Table 3. Monocular UDVA improved substantially in all four IOL power groups after implantation. At 3 months, mean monocular UDVA was comparable across groups (0.21±0.28, 0.11±0.21, 0.13±0.21, and 0.10±0.17 logMAR in Groups 1 to 4, respectively; $p=0.498$). Monocular UIVA (at 80 cm and 66 cm) and

Table 3 Monocular and Binocular Visual Acuity at Distance, Intermediate, and Near at 1 and 3 Months After Surgery Stratified by IOL Power Groups

		N	Monocular VA (logMAR)				
			Group 1 (<20.0 D)	Group 2 (20.0–21.5 D)	Group 3 (22.0–23.5 D)	Group 4 (≥24.0 D)	Inter-group p-value
UDVA (far)	1M	304	0.26±0.32	0.12±0.23	0.12±0.23	0.14±0.24	0.2524
	3M	208	0.21±0.28	0.11±0.21	0.13±0.21	0.10±0.17	0.4978
UIVA (80 cm)	1M	278	0.27±0.07	0.28±0.07	0.30±0.10	0.28±0.08	0.5396
	3M	166	0.26±0.06	0.26±0.07	0.25±0.05	0.26±0.06	0.9405
UIVA (66 cm)	1M	278	0.40±0.07	0.41±0.08	0.41±0.08	0.40±0.08	0.8308
	3M	166	0.39±0.08	0.40±0.08	0.38±0.07	0.40±0.07	0.6430
UNVA (40 cm)	1M	278	0.60±0.08	0.61±0.10	0.58±0.10	0.60±0.10	0.3758
	3M	166	0.57±0.08	0.58±0.09	0.56±0.07	0.58±0.09	0.6164
		N	Binocular VA (logMAR)				
			Group 1 (<20.0 D)	Group 2 (20.0–21.5 D)	Group 3 (22.0–23.5 D)	Group 4 (≥24.0 D)	Inter-group p-value
UIVA (80 cm)	1M	107	0.17±0.06	0.21±0.12	0.20±0.14	0.20±0.07	0.4670
	3M	67	0.17±0.07	0.17±0.09	0.15±0.05	0.19±0.10	0.5990
UIVA (66 cm)	1M	107	0.30±0.06	0.30±0.07	0.32±0.10	0.31±0.08	0.6920
	3M	67	0.30±0.06	0.29±0.08	0.28±0.07	0.30±0.08	0.8710
UNVA (40 cm)	1M	107	0.48±0.08	0.49±0.11	0.47±0.08	0.49±0.10	0.7640
	3M	67	0.48±0.06	0.46±0.09	0.46±0.10	0.47±0.09	0.9320

Notes: Inter-group p-values for monocular visual acuity outcomes were calculated using generalized estimating equations (GEE) with an exchangeable correlation structure to account for within-subject correlation between fellow eyes (304 eyes from 216 patients). Binocular visual acuity outcomes were analyzed using one-way analysis of variance (ANOVA). Data are presented as mean ± standard deviation (SD) in logarithm of the minimum angle of resolution (logMAR).

Abbreviations: N, numbers of eyes; logMAR, logarithm of the minimum angle of resolution; UDVA/UIVA/UNVA, uncorrected distance/intermediate/near visual acuity; D, diopters; 1M/3M, 1 month/3 months postoperatively.

UNVA (at 40 cm) showed no significant inter-group differences at both 1 and 3 months (all $p>0.23$). Binocular UIVA and UNVA were likewise comparable across all groups at both time points (all $p\geq 0.467$).

Cumulative Snellen analysis ([Figure 1](#)) confirmed high efficacy irrespective of IOL power. At 3 months, over 85% of eyes in every group achieved monocular UDVA of 20/40 or better, while CDVA of 20/20 or better was attained in over 92% of eyes across all groups.

Photopic monocular and binocular defocus curves at 1 and 3 months ([Figure 2](#)) demonstrated similar depth of focus across the four IOL-power groups. The curves overlapped closely at most defocus levels, with no statistically significant inter-group differences (GEE, $p>0.05$ for the majority of comparisons). Mesopic defocus curves at 1 month ([Supplementary Figure 1](#)) exhibited the same consistent pattern.

Visual Quality Outcomes

Internal HOAs are summarized in [Table 4](#). Postoperative SA and coma RMS values remained low across all four IOL power groups and showed no significant inter-group differences at 1 or 3 months (all $p>0.18$). Postoperative SA values were consistently near zero (approximately -0.008 to $+0.006$ μm). A nominal difference in coma H observed at 1 month was no longer present at 3 months ($p=0.203$).

Photopic CS measured with the CSV-1000E at 1 month is presented in [Supplementary Figure 2](#). Low- and mid-spatial-frequency CS were comparable across groups for both monocular and binocular testing. Although a nominal inter-group

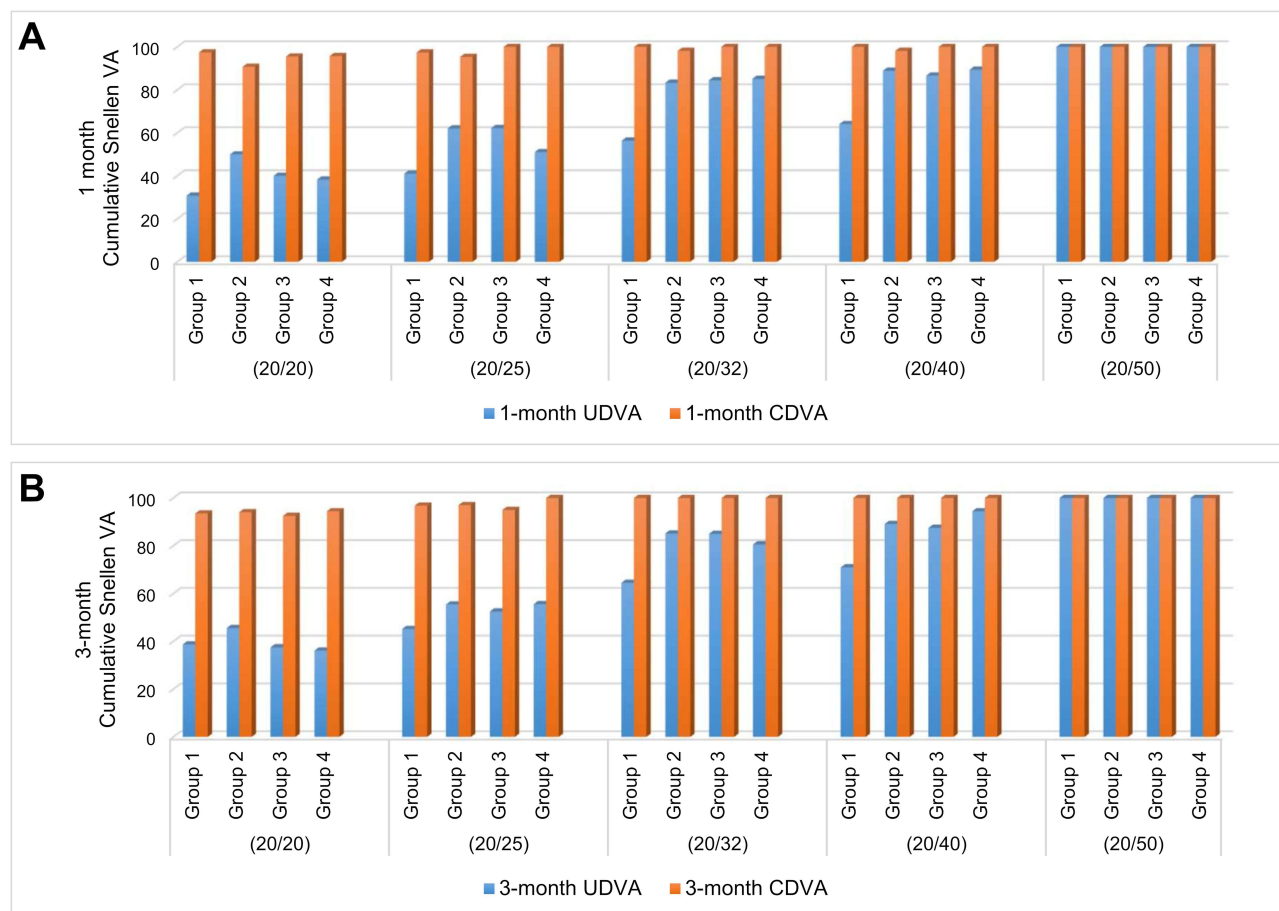


Figure 1 Cumulative percentage of eyes achieving specified visual acuity thresholds at 1 and 3 months post-surgery. Cumulative percentage of eyes reaching or exceeding Snellen visual acuity thresholds for monocular uncorrected distance visual acuity (UDVA) and corrected distance visual acuity (CDVA) at 1 month (A) and 3 months (B). Group 1 (<20.0 diopters [D]), Group 2 (20.0–21.5 D), Group 3 (22.0–23.5 D), Group 4 (≥24.0 D). No significant inter-group differences were observed ($p>0.05$ by generalized estimating equations [GEE]). **Abbreviation:** VA, visual acuity; UDVA/CDVA, uncorrected/corrected distance visual acuity.

difference appeared at monocular 3 cpd ($p=0.0337$), no consistent differences were found at any other spatial frequencies (all remaining $p>0.078$).

Adjusted Analyses and Correlations

GEE analyses adjusted for age, gender, and pupil size are shown in Table 5. After adjustment, IOL power group had no independent effect on 3-month UDVA ($p=0.666$) or on any internal HOA (SA, $p=0.925$; coma $p>0.17$). Partial correlation analyses controlling for age and gender demonstrated a modest positive association between IOL power (continuous variable) and high-spatial-frequency CS at 1 month (12–18 cpd; partial $r=0.38$, $p=0.008$). Pupil size itself showed no meaningful correlation with UDVA, HOAs, or CS after adjustment (Supplementary Table 1; all $|r|<0.3$, $p>0.05$).

Discussion

This retrospective IOL power-stratified analysis of 304 eyes implanted with the ZEISS CT LUCIA 621P IOL is the first to systematically evaluate refractive predictability, VA (including defocus curves), and optical quality (HOAs and CS) across four clinically relevant power groups (<20.0 D, 20.0–21.5 D, 22.0–23.5 D, ≥24 D). Despite marked baseline differences in AL, preoperative refraction, gender distribution, and pupil size (all $p<0.001$ except age and CDVA), postoperative outcomes converged toward excellent and comparable results at 1 and 3 months. After GEE adjustment for age, gender, and pupil size, the IOL-power groups exerted no independent effect on UDVA or internal HOAs, supporting the consistent performance of the lens's gradient aspheric ZEISS Optic design across a wide range of biometric profiles.^{5–7}

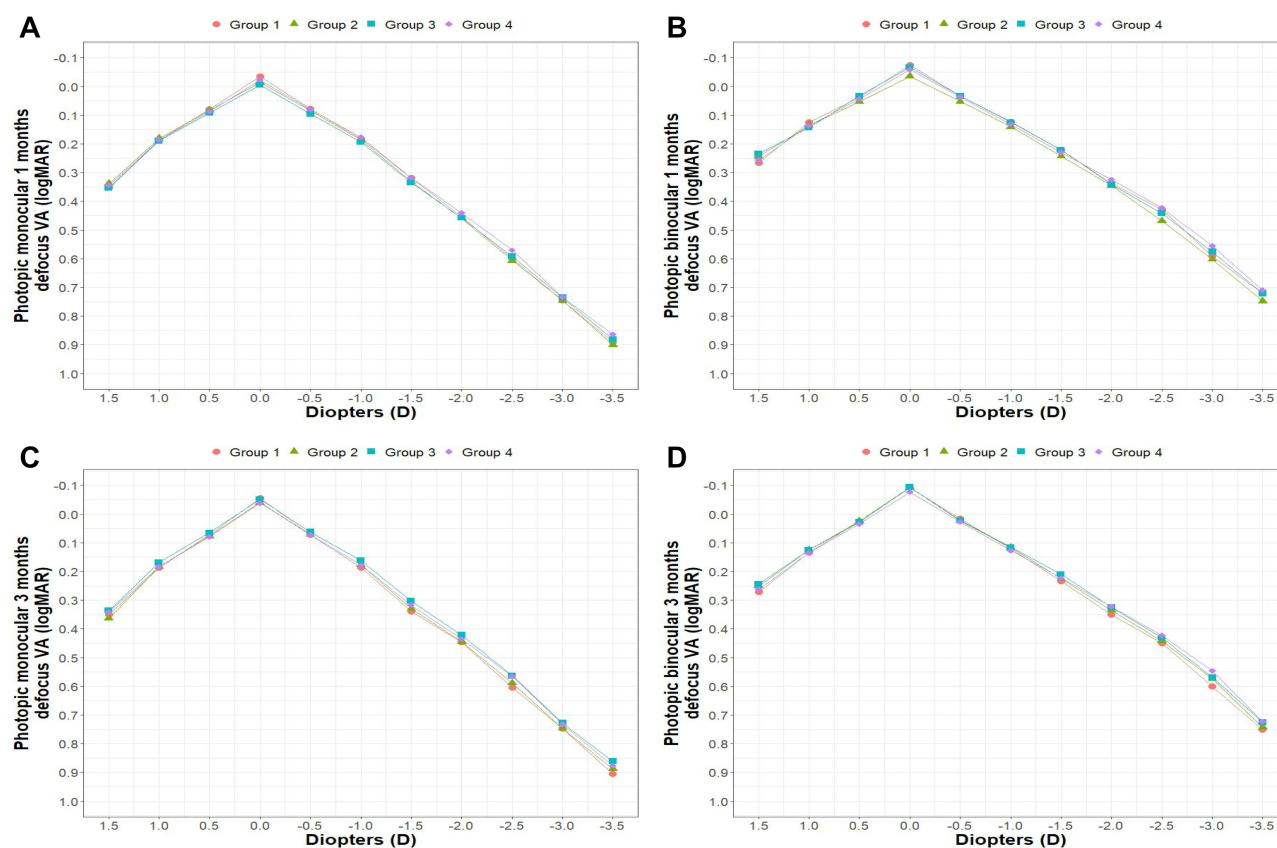


Figure 2 Photopic defocus curves at 1 and 3 months post-surgery. Mean monocular (left panels) and binocular (right panels) photopic defocus curves at 1 month (A and B) and 3 months (C and D). Group 1 (<20.0 D), Group 2 (20.0–21.5 D), Group 3 (22.0–23.5 D), Group 4 (≥ 24.0 D). No significant inter-group differences were observed at most defocus levels ($p > 0.05$ by generalized estimating equations [GEE]).

Abbreviation: VA, visual acuity; logMAR, logarithm of the minimum angle of resolution.

Although monovision strategies are increasingly used with monofocal IOLs, all eyes in this cohort were targeted for emmetropia, with outcomes converging toward it across all groups. Consequently, the observed defocus and intermediate performance reflect the lens' intrinsic optical properties rather than intentional refractive strategies such as monovision.¹¹

Table 4 Internal HOAs at 1 and 3 Months Post-Surgery for Four Groups

Parameter		N	LUCIA621P Four Groups				Inter-group p-value
			Group 1 (<20.0 D)	Group 2 (20.0–21.5 D)	Group 3 (22.0–23.5 D)	Group 4 (≥ 24.0 D)	
SA (RMS)	pre	298	0.022 $\pm$ 0.122	0.026 $\pm$ 0.156	0.044 $\pm$ 0.129	0.017 $\pm$ 0.080	0.6618
	1M	278	0.008 $\pm$ 0.076	–0.006 $\pm$ 0.045	0.010 $\pm$ 0.080	–0.008 $\pm$ 0.048	0.2866
	3M	180	0.006 $\pm$ 0.056	–0.006 $\pm$ 0.074	–0.005 $\pm$ 0.061	0.002 $\pm$ 0.130	0.7983
Coma H (RMS)	pre	298	0.024 $\pm$ 0.115	0.022 $\pm$ 0.196	0.013 $\pm$ 0.136	0.023 $\pm$ 0.134	0.9635
	1M	78	0.015 $\pm$ 0.058	0.011 $\pm$ 0.062	–0.021 $\pm$ 0.148	–0.016 $\pm$ 0.066	0.0378
	3M	180	0.004 $\pm$ 0.085	0.000 $\pm$ 0.068	–0.016 $\pm$ 0.052	0.020 $\pm$ 0.171	0.2038
Coma V (RMS)	pre	298	–0.015 $\pm$ 0.165	–0.014 $\pm$ 0.214	–0.037 $\pm$ 0.26	–0.009 $\pm$ 0.171	0.9244
	1M	278	0.018 $\pm$ 0.129	–0.002 $\pm$ 0.086	0.016 $\pm$ 0.117	–0.016 $\pm$ 0.080	0.2200
	3M	180	0.026 $\pm$ 0.088	–0.006 $\pm$ 0.079	0.011 $\pm$ 0.088	–0.020 $\pm$ 0.106	0.1800

Note: Inter-group p-values were calculated using generalized estimating equations (GEE) with an exchangeable correlation structure to account for within-subject correlation between fellow eyes. Data are presented as mean $\pm$ standard deviation (SD).

Abbreviations: N, number of eyes; HOAs, higher-order aberrations; SA, spherical aberration; Coma H/V, horizontal/vertical coma; RMS, root mean square; D, diopters; pre, preoperative; 1M/3M, 1 month/3 months postoperatively.

Table 5 GEE Analysis of 3-Month Postoperative Outcomes Adjusted for Age, Gender, and Pupil Size

Parameter	Group	N	Adjusted Mean	SE	95% CI	p-value (Group effect)
UDVA (logMAR)	Group 1 (<20.0 D)	31	0.176	0.038	0.101–0.252	0.6655
	Group 2 (20.0–21.5 D)	101	0.107	0.020	0.066–0.147	
	Group 3 (22.0–23.5 D)	40	0.136	0.033	0.072–0.200	
	Group 4 ($\geq$ 24.0 D)	36	0.132	0.035	0.062–0.202	
SA (RMS)	Group 1 (<20.0 D)	26	–0.003	0.017	–0.037–0.031	0.9246
	Group 2 (20.0–21.5 D)	84	–0.008	0.009	–0.026–0.010	
	Group 3 (22.0–23.5 D)	38	–0.002	0.013	–0.029–0.024	
	Group 4 ($\geq$ 24.0 D)	32	0.005	0.015	–0.025–0.035	
Coma H (RMS)	Group 1 (<20.0 D)	26	0.004	0.020	–0.036–0.043	0.2103
	Group 2 (20.0–21.5 D)	84	–0.001	0.011	–0.021–0.020	
	Group 3 (22.0–23.5 D)	38	–0.016	0.016	–0.047–0.015	
	Group 4 ($\geq$ 24.0 D)	32	0.021	0.018	–0.013–0.056	
Coma V (RMS)	Group 1 (<20.0 D)	26	0.023	0.018	–0.013–0.059	0.2197
	Group 2 (20.0–21.5 D)	84	–0.006	0.010	–0.025–0.013	
	Group 3 (22.0–23.5 D)	38	0.013	0.014	–0.015–0.041	
	Group 4 ($\geq$ 24.0 D)	32	–0.024	0.016	–0.056–0.007	

Note: Generalized estimating equations (GEE) models with an exchangeable correlation structure were used. All models were adjusted for age, gender, and pupil size. Adjusted means, standard errors (SE), and 95% confidence intervals (CI) are presented. p-values indicate the significance of the IOL power group effect after GEE adjustment. All data are from 3-month postoperative measurements.

Abbreviation: N, number of eyes; SE, standard errors; CI, confidence intervals; UNVA, uncorrected distance visual acuity; logMAR, logarithm of the minimum angle of resolution; SA, spherical equivalent; Coma H/V, horizontal/vertical coma; RMS, root mean square; D, diopters.

Refractive outcomes demonstrated clear convergence toward emmetropia in all groups. Preoperative SE, SPH, and CYL differed substantially between groups as expected from biometric stratification, yet at 3 months mean SE ranged only from -0.83 ± 0.81 D (Group 1) to -0.48 ± 0.68 D (Group 4) with no significant inter-group difference ($p=0.398$) (Table 2). These findings are consistent with previous single-cohort studies of the CT LUCIA 621P, which reported 84.8–92.7% of eyes within ± 0.50 D of target and mean SE between -0.03 D and -0.18 D.^{1,10,12} In conventional fixed-aspheric IOLs, increasing lens power is associated with steeper curvature and greater intrinsic SA. The observed stability in SA across groups suggests that the non-constant aspheric profile effectively compensates for these geometric changes, maintaining a near-zero postoperative aberration state.^{2,9}

VA improved substantially and remained consistent across all distances and lighting conditions irrespective of IOL power. At 3 months, monocular UDVA was comparable between groups (0.21 ± 0.28 to 0.10 ± 0.17 logMAR; $p=0.498$), as were monocular and binocular UIVA and UNVA (all $p>0.23$) (Table 3). Cumulative Snellen analysis showed that $>92\%$ of eyes achieved CDVA of 20/20 or better (Figure 1), while photopic and mesopic defocus curves overlapped closely across groups (GEE $p>0.05$ for the majority of comparisons), demonstrating a flat, power-independent depth of focus (Figure 2 and Supplementary Figure 1). These results align with earlier reports of the CT LUCIA 621P (monocular UDVA 0.05–0.09 logMAR and 74.9–94.5% of eyes $\geq 20/25$),^{8,10,13} but extend them by confirming that the excellent visual performance persists even in extreme power ranges where fixed-aspheric IOLs typically show reduced defocus tolerance.^{3,14} The relatively flat defocus curve observed across all power groups suggests to extended depth of focus designs, this characteristic may provide functional tolerance to small refractive errors in daily visual tasks. The power-independent flat defocus curve observed in this study is attributable to the optical profile of the lens.^{6,7,15}

Optical quality was well preserved regardless of implanted IOL power. Postoperative internal SA remained near zero (approximately -0.008 to $+0.006$ μ m RMS) across all groups with no significant inter-group differences (GEE-adjusted $p=0.925$), and coma RMS values were also comparable (all $p>0.18$) (Table 4). Photopic CS at low- and mid-spatial

frequencies was similar between groups; although a nominal difference appeared at monocular 3 cpd ($p=0.0337$), it did not persist at high frequencies or binocularly ([Supplementary Figure 2](#)). The modest positive association between IOL power and high-spatial-frequency CS may partly reflect smaller pupil sizes in higher-power groups, which reduce HOAs and improve retinal image quality.¹⁶

The gradient aspheric design—mild negative SA centrally transitioning to near-neutral peripherally—accounts for this maintenance of optical quality despite the increased thickness and curvature inherent to higher-power IOLs.^{5–7,15} This design optimizes the aspheric profile during manufacturing to manage power-dependent variations (including longitudinal SA [LSA]), thereby delivering stable aberration control across the entire dioptric range without the degradation typically seen in fixed-aspheric lenses.

Pupil size, a known modifier of HOAs and CS,¹⁷ showed no meaningful correlation with any key outcomes after adjustment for age and gender ($|r|<0.3$, $p>0.05$; [Supplementary Table 1](#)), further validating its inclusion as a covariate in the GEE models.

Strengths of the study include its first-in-kind power-stratified approach with multidimensional outcomes, rigorous confounder adjustment via GEE and partial correlations, and real-world applicability in a consecutive series. Limitations are as follows. First, it was retrospective and single-centered. Second, the maximum follow-up was only 3 months, CS was measured only at 1 month, and patient-reported outcome measures were not collected. Although the maximum follow-up was limited to 3 months, this represents a time point at which refractive error and monocular VA are generally stable after cataract surgery. This interval was selected to obtain early comparative performance data and is consistent with prior early-phase clinical studies.¹⁸ Third, sample sizes in the extreme power groups were relatively modest. Larger multicenter studies with extended follow-up and patient-reported outcomes would provide valuable additional insights.

Conclusion

In conclusion, the ZEISS CT LUCIA 621P IOL with its unique non-constant aspheric optic delivered predictable refractive outcomes, excellent VA at all distances, and minimal HOAs irrespective of lens power. These findings provide clinically meaningful evidence that this gradient aspheric design effectively overcomes the power-dependent limitations of conventional monofocal IOLs, offering surgeons greater confidence in achieving optimal outcomes across the full spectrum of cataract patients.

Abbreviations

CDVA, corrected distance visual acuity; CS, contrast sensitivity; CYL, cylindrical power; D, diopters; GEE, generalized estimating equations; coma H/V, horizontal/vertical coma; HOA, higher-order aberration; IOL, intraocular lens; logMAR, logarithm of the minimum angle of resolution; RMS, root mean square; SA, spherical aberration; SE, spherical equivalent; SPH, spherical power; UDVA, uncorrected distance visual acuity; UIVA, uncorrected intermediate visual acuity; UNVA, uncorrected near visual acuity.

Data Sharing Statement

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Acknowledgments

We express gratitude to the Fatima Eye Clinic staff for their assistance in data collection and patient care.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Funding

No financial disclosures to declare for this work.

Disclosure

The authors report no conflicts of interest in this work.

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