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Comparison of clinical outcomes between monofocal and multifocal intraocular lens implantation after implantable Collamer lens removal combined with cataract surgery

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Abstract

Background: Patients developing cataracts after implantable Collamer lens (ICL) implantation represent a unique population requiring careful intraocular lens (IOL) selection. This study compared clinical outcomes between monofocal IOL (SIOL) and multifocal IOL (MIOL) implantation after ICL removal combined with cataract surgery.

Methods: This prospective case series included 70 eyes from 70 patients who underwent ICL removal combined with femtosecond laser-assisted cataract surgery (FLACS). The MIOL group (31 eyes) received ZEISS AT LISA tri 839MP trifocal IOL targeting emmetropia, while the SIOL group (39 eyes) received ZEISS CT ASPHINA 409MP monofocal IOL with intentional myopic target of -2.00D to -3.00D. Comprehensive ophthalmic examinations were performed preoperatively and at 1 month postoperatively, including visual acuity, defocus curve, objective visual quality parameters, and patient questionnaires.

Results: The MIOL group achieved significantly better uncorrected distance visual acuity (UDVA) (0.02±0.04 LogMAR) compared to the SIOL group (0.35±0.15 LogMAR) ($P<0.001$), as expected due to the intentional myopic target. However, corrected distance visual acuity (CDVA) showed no significant difference between groups (0.00±0.02 vs 0.01±0.03 LogMAR, $P=0.562$). The MIOL group demonstrated a distinct "defocus plateau" from 0D to -3D. Postoperative MTF-10 was 0.31±0.12 in the MIOL group and 0.35±0.14 in the SIOL group ($P=0.042$). Postoperative MTF-30 was 0.12±0.05 and 0.15±0.06, respectively ($P=0.038$). Postoperative Strehl ratio was 0.09±0.07 and 0.11±0.04, respectively. The MIOL group showed higher spectacle independence rates.

Conclusions: MIOL implantation provides excellent uncorrected distance vision and full-range vision with high spectacle independence. SIOL implantation with myopic target results in poorer uncorrected distance vision but comparable corrected distance vision and superior optical quality. Both IOL types have distinct advantages, and selection should be individualized.

Introduction

Phakic intraocular lens (pIOL) implantation has become an established surgical option for correcting high myopia, with the implantable Collamer lens (ICL) gaining widespread adoption due to its favorable predictability and reversibility [1]. However, as patients with ICLs age, some develop lens opacification necessitating ICL removal combined with cataract extraction [2]. These patients present unique clinical characteristics including a history of high myopia, elongated axial length, abnormal corneal curvature, and high expectations for postoperative visual quality [3].

The selection of intraocular lens (IOL) is a critical determinant of postoperative visual outcomes. Monofocal IOLs (SIOLs) provide excellent distance vision but typically require reading glasses for near tasks [4]. Multifocal IOLs (MIOLs) employ optical designs to achieve vision across distance, intermediate, and near ranges, potentially reducing spectacle dependence [5]. However, MIOLs may induce photic phenomena such as glare and halos, with possible reduction in contrast sensitivity [6].

Previous studies have predominantly focused on IOL selection in primary cataract patients, with limited research addressing ICL patients developing cataracts [7]. These patients have undergone prior intraocular surgery, potentially altering ocular anatomy, and often have heightened expectations for visual quality, necessitating more careful IOL selection [8]. Femtosecond laser-assisted cataract surgery (FLACS) offers advantages including precise incisions, well-centered capsulotomies, and reduced ultrasound energy, potentially contributing to improved visual outcomes [9].

This study aims to compare clinical outcomes between SIOL and MIOL implantation after ICL removal combined with FLACS, evaluating differences in visual recovery, objective visual quality, and patient satisfaction to provide evidence for clinical decision-making.

Methods

Study design and patients

This prospective case series was conducted at Shanghai Heping Eye Hospital. The study included patients who underwent ICL removal combined with FLACS between April 2024 and January 2026. Inclusion criteria were: (1) history of ICL implantation; (2) lens opacification causing visual impairment with surgical indication; (3) complete postoperative follow-up data. Exclusion criteria were: (1) coexisting ocular diseases affecting vision such as corneal pathology, glaucoma, or retinal disease; (2) intraoperative or postoperative severe complications; (3) loss to follow-up.

Based on patient preference and preoperative evaluation, patients were divided into MIOL and SIOL groups. The MIOL group comprised 31 eyes from 31 patients (12 males, 19 females) with age ranging from 36 to 65 years (mean 52.3 ± 8.2 years). The SIOL group comprised 39 eyes from 39 patients (15 males, 24 females) with age ranging from 29 to 62 years (mean 46.5 ± 9.1 years).

The study was approved by the Institutional Review Board of Shanghai Heping Eye Hospital and adhered to the tenets of the Declaration of Helsinki. All patients provided written informed consent.

Surgical technique

All surgeries were performed by a single experienced cataract surgeon. Preoperative examinations included uncorrected visual acuity, best-corrected visual acuity, intraocular pressure, slit-lamp examination, fundus examination, and biometry (IOLMaster 700, Carl Zeiss Meditec, Germany).

FLACS was performed using the CATALYS femtosecond laser system (Johnson & Johnson Vision, Santa Ana, CA, USA) for corneal incisions, anterior capsulotomy, and lens fragmentation. ICL removal was performed first: a clear corneal incision was created at the limbus, viscoelastic was injected into the anterior chamber, and the ICL was loosened using a manipulator and extracted through the incision. Subsequently, phacoemulsification was performed using the Centurion phacoemulsification system

(Alcon Laboratories, Fort Worth, TX, USA) for nuclear emulsification and cortical aspiration. After complete cortical removal, a preloaded capsular tension ring (ACPi-11, Corneal, France; distributed by Bausch + Lomb) was implanted in all patients to maintain capsular stability and ensure IOL centration. After viscoelastic injection into the capsular bag, the IOL was implanted using an injector and centered. Viscoelastic was removed, and the incision was hydrated.

The MIOL group received ZEISS AT LISA tri 839MP (Carl Zeiss Meditec, Germany) trifocal IOL with target refraction of emmetropia (spherical equivalent 0.00D). The SIOL group received ZEISS CT ASPHINA 409MP (Carl Zeiss Meditec, Germany) monofocal IOL with target refraction of -2.00D to -3.00D myopia to meet patients' near vision needs.

Outcome measures

Uncorrected distance visual acuity (UDVA) and corrected distance visual acuity (CDVA) were measured preoperatively and at 1 day, 1 week, and 1 month postoperatively.

At 1 month postoperatively, the defocus curve was measured for the MIOL group using an automated projection visual acuity chart. Patients wore optimal distance correction, and visual acuity was measured from + 2.00D to -4.00D in 0.50D increments.

Objective visual quality parameters were measured using the iTrace Visual Function Analyzer (Tracey Technologies, USA), including higher-order aberration (HOA) and modulation transfer function cutoff (MTF cutoff, including MTF-10 and MTF-30), and Strehl Ratio (SR).

Postoperative questionnaires at 1 month included a study-specific spectacle independence and satisfaction survey (Supplementary File 1). The survey was developed for this study to assess patients' dependence on spectacles for distance, intermediate, and near activities, as well as overall satisfaction with surgical outcomes.

Statistical analysis

Statistical analysis was performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean±standard deviation and compared using independent samples t-test or Mann-Whitney U test. Categorical variables were expressed as frequency (percentage) and compared using chi-square test or Fisher's exact test. $P < 0.05$ was considered statistically significant.

Results

Baseline characteristics

Baseline characteristics are presented in Table 1. No statistically significant differences were found between the MIOL and SIOL groups in age, gender distribution, axial length, anterior chamber depth, or

corneal curvature (P > 0.05).

Table 1
Comparison of baseline characteristics between groups

Parameter	MIOL Group (n = 31 eyes)	SIOL Group (n = 39 eyes)	P value
Age (years, mean ± SD)	52.3 ± 8.2	46.5 ± 9.1	0.078
Axial length (mm, mean ± SD)	31.85 ± 1.35	32.12 ± 1.87	0.512
Anterior chamber depth (mm, mean ± SD)	3.05 ± 0.31	3.02 ± 0.28	0.672
K1 (D, mean ± SD)	42.15 ± 2.35	42.68 ± 1.82	0.312
K2 (D, mean ± SD)	43.28 ± 2.56	43.05 ± 2.18	0.685
White-to-white (mm, mean ± SD)	12.05 ± 0.25	11.92 ± 0.28	0.052
Lens thickness (mm, mean ± SD)	4.58 ± 0.42	4.45 ± 0.38	0.185

MIOL: Multifocal intraocular lens; SIOL: Monofocal intraocular lens; SD: Standard deviation; K1: Keratometry 1; K2: Keratometry 2.

Postoperative visual acuity

At 1 month postoperatively, the MIOL group achieved a mean UDVA of 0.02 ± 0.04 LogMAR, while the SIOL group achieved 0.35 ± 0.15 LogMAR, with the SIOL group showing significantly worse UDVA (P < 0.001). This result was expected as the SIOL group had intentional myopic target of -2.00D to -3.00D. However, CDVA showed no significant difference between groups: MIOL group 0.00 ± 0.02 LogMAR vs SIOL group 0.01 ± 0.03 LogMAR (P = 0.562). In the MIOL group, 71.0% (22/31 eyes) achieved UDVA of 0.00 LogMAR, compared to 0% (0/39 eyes) in the SIOL group. However, 87.2% (34/39 eyes) in the SIOL group achieved CDVA of 0.00 LogMAR.

Defocus curve results for the MIOL group are presented in Fig. 1. The defocus curve demonstrated optimal vision at 0D (distance) with LogMAR of 0.02. Within the − 0.5D to -3D range, visual acuity maintained at LogMAR 0.05–0.18, forming a distinct "defocus plateau" indicative of favorable intermediate vision. At -3.5D to -4D (near distance), visual acuity decreased to LogMAR 0.32–0.47. The SIOL group, due to intentional myopic target, had good uncorrected near vision, achieving LogMAR 0.10–0.20 at -2D to -3D range.

Objective visual quality

Preoperative and postoperative objective visual quality parameters are presented in Table 2. Postoperative HOA was 0.52 ± 0.28 μm in the MIOL group and 0.38 ± 0.21 μm in the SIOL group (P =

0.025). Postoperative MTF-10 was 0.31 ± 0.12 in the MIOL group and 0.35 ± 0.14 in the SIOL group, with significant difference (P = 0.042). Postoperative MTF-30 was 0.12 ± 0.05 in the MIOL group and 0.15 ± 0.06 in the SIOL group, with significant difference (P = 0.038). Postoperative SR was 0.09 ± 0.07 in the MIOL group and 0.11 ± 0.04 in the SIOL group. Comparison of objective visual quality parameters is shown in Fig. 2.

Table 2
Comparison of objective visual quality parameters between groups

Parameter	MIOL Group (n = 31 eyes)	SIOL Group (n = 39 eyes)	P value
Preoperative HOA (μm)	0.68 ± 0.42	0.62 ± 0.38	0.528
Postoperative HOA (μm)	0.52 ± 0.28	0.38 ± 0.21	0.025
Preoperative MTF-10	0.12 ± 0.08	0.14 ± 0.09	0.352
Postoperative MTF-10	0.31 ± 0.12	0.35 ± 0.14	0.042
Preoperative MTF-30	0.04 ± 0.03	0.05 ± 0.04	0.285
Postoperative MTF-30	0.12 ± 0.05	0.15 ± 0.06	0.038
Postoperative SR	0.09 ± 0.07	0.11 ± 0.04	0.562

MIOL: Multifocal intraocular lens; SIOL: Monofocal intraocular lens; HOA: Higher-order aberration; MTF: Modulation transfer function; SR: Strehl ratio.

Questionnaire results

Spectacle independence survey results showed that the MIOL group had complete spectacle independence rates of 58.1% (18/31) for distance activities versus 38.5% (15/39) in the SIOL group. For intermediate activities, the MIOL group had 51.6% (16/31) complete independence versus 33.3% (13/39) in the SIOL group. For near activities, the MIOL group had 48.4% (15/31) complete independence versus 20.5% (8/39) in the SIOL group. Overall spectacle independence was higher in the MIOL group (Fig. 3). Notably, the SIOL group had good uncorrected near vision due to intentional myopic target, but required myopic glasses for distance activities.

Patient satisfaction surveys showed that 74.2% (23/31) of the MIOL group was "very satisfied" with surgical outcomes, 19.4% (6/31) was "satisfied," and 6.4% (2/31) was "neutral." In the SIOL group, 64.1% (25/39) was "very satisfied," 28.2% (11/39) was "satisfied," and 7.7% (3/39) was "neutral." No significant difference was found between groups (P = 0.762).

Discussion

Patients developing cataracts after ICL implantation represent a unique population requiring careful IOL selection [10]. This prospective study compared clinical outcomes between SIOL and MIOL implantation

after ICL removal combined with FLACS, finding that both IOL types have distinct advantages: the MIOL group achieved excellent uncorrected distance vision and full-range vision with high spectacle independence; the SIOL group, despite poorer uncorrected distance vision due to intentional myopic target, achieved comparable corrected distance vision and superior optical quality.

In this study, the MIOL group achieved significantly better UDVA (LogMAR 0.02 ± 0.04) compared to the SIOL group (LogMAR 0.35 ± 0.15), as the SIOL group had intentional myopic target of -2.00D to -3.00D. However, CDVA showed no significant difference between groups, indicating equivalent optical correction with both IOL types. This finding suggests that patients choosing SIOL can achieve clear distance vision with myopic glasses while retaining good uncorrected near vision.

The MIOL group demonstrated a distinct "defocus plateau" maintaining good vision from 0D to -3D, related to the optical design of ZEISS AT LISA tri 839MP [11]. This trifocal IOL employs diffractive optical design with near addition of + 3.33D and intermediate addition of + 1.66D, enabling vision across distance, intermediate, and near ranges [12].

Objective visual quality assessment showed that the SIOL group demonstrated significantly better postoperative MTF-10 and MTF-30 values compared to the MIOL group. MTF (modulation transfer function) is a critical parameter for evaluating optical system imaging quality, describing the ability of an optical system to transfer contrast from object to image [17]. In ophthalmology, MTF is typically described as a function of spatial frequency, measured in cycles per degree (cpd), reflecting the fineness of resolvable details in retinal imaging [18].

MTF-10 and MTF-30 represent modulation transfer function values at different spatial frequencies with distinct clinical significance. MTF-10 represents contrast transfer at 10 cycles per degree, a low spatial frequency primarily reflecting imaging capability in low-contrast environments, closely related to contrast perception in daily life [19]. Higher MTF-10 values indicate stronger ability to transfer low-frequency information and better imaging contrast. MTF-30 represents modulation transfer at 30 cycles per degree, a high spatial frequency primarily reflecting the optical system's ability to resolve fine details [20]. Higher MTF-30 values indicate better resolution of fine details, closely related to fine visual tasks such as reading small text [21].

Strehl Ratio (SR) is another important parameter for optical system imaging quality, defined as the ratio of actual optical system point source image center intensity to ideal diffraction-limited system point source image center intensity [22]. SR values range from 0 to 1, with values closer to 1 indicating imaging quality closer to ideal. In this study, postoperative SR was 0.09 ± 0.07 in the MIOL group and 0.11 ± 0.04 in the SIOL group, with no significant difference.

The results align with optical characteristics of MIOLs, which distribute incoming light to different focal points through diffractive optical design, inevitably reducing light energy at each focus and affecting contrast transfer and detail resolution [24]. Previous studies have confirmed that MIOLs have certain disadvantages in contrast sensitivity and low-contrast visual acuity [25]. However, this reduction in

optical quality is acceptable to most patients, especially considering the full-range vision advantage and higher spectacle independence provided by MIOLs.

Patient satisfaction is a key indicator for successful IOL selection. In this study, both groups demonstrated high satisfaction, with the MIOL group showing slightly higher "very satisfied" rates (74.2% vs 64.1%), though the difference was not statistically significant, possibly related to higher spectacle independence in the MIOL group.

Spectacle independence is a primary advantage of MIOLs. In this study, the MIOL group had higher complete spectacle independence rates across distance, intermediate, and near ranges compared to the SIOL group, with particularly notable differences in near vision independence (48.4% vs 20.5%) [26]. However, spectacle independence is influenced by multiple factors including occupation, lifestyle, and visual quality expectations [27]. Notably, the SIOL group had good uncorrected near vision due to intentional myopic target but required myopic glasses for distance activities, which patients should fully understand when choosing SIOL.

All surgeries in this study were performed with CATALYS femtosecond laser assistance, using the Centurion phacoemulsification system for lens removal, with preloaded capsular tension rings (ACPi-11, Corneal, France; distributed by Bausch + Lomb) implanted in all patients. FLACS offers multiple advantages: precise corneal incisions reduce surgically induced astigmatism; centered anterior capsulotomy ensures IOL centration, particularly important for MIOLs; pre-fragmentation reduces ultrasound energy, lowering risk of corneal endothelial damage [9]. Capsular tension ring implantation helps maintain capsular stability, especially for potential capsular laxity after ICL removal, ensuring IOL centration and improving postoperative visual quality [28].

IOL selection for cataract patients after ICL implantation requires individualized consideration. For patients seeking full-range vision with reduced spectacle dependence, ZEISS AT LISA tri 839MP is a favorable choice; for patients accustomed to near work, sensitive to visual disturbances, or prioritizing optical quality, ZEISS CT ASPHINA 409MP with myopic target may be more appropriate [29]. Comprehensive preoperative examination and patient communication are essential, fully informing patients of the advantages and disadvantages of each IOL type and expected visual outcomes, making selections based on patient needs and expectations [30].

This study has several limitations. First, the short follow-up period precluded assessment of long-term outcomes. Second, detailed visual function assessments such as contrast sensitivity were not performed. Third, the sample size was limited, potentially affecting statistical power. Future prospective studies with larger sample sizes and longer follow-up are needed for validation.

Conclusions

Implantation of ZEISS AT LISA tri 839MP MIOL after ICL removal combined with FLACS provides excellent uncorrected distance vision and full-range vision with high spectacle independence and patient

satisfaction. Implantation of ZEISS CT ASPHINA 409MP SIOL with myopic target results in poorer uncorrected distance vision but comparable corrected distance vision and superior optical quality with higher MTF-10 and MTF-30 values. Both IOL types have distinct advantages, and clinical selection should be individualized based on patient needs, ocular conditions, and economic circumstances. Thorough preoperative communication and appropriate expectation setting are key to ensuring patient satisfaction.

Abbreviations

ICL
Implantable Collamer lens
IOL
Intraocular lens
SIOL
Monofocal intraocular lens
MIOL
Multifocal intraocular lens
FLACS
Femtosecond laser-assisted cataract surgery
UDVA
Uncorrected distance visual acuity
CDVA
Corrected distance visual acuity
HOA
Higher-order aberration
MTF
Modulation transfer function
SR
Strehl ratio

Declarations

Ethics approval and consent to participate

The study was approved by the Institutional Review Board of Shanghai Heping Eye Hospital and adhered to the tenets of the Declaration of Helsinki. All patients provided written informed consent.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Author Contribution

SN wrote the main manuscript text.YJ reviewed the manuscript.XC prepared tables 1-2.ZZ prepared figures 1-3.XW reviewed the manuscript.HG: Conceptualization,Methodology, Project administration Supervision.

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Availability of data and materials

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

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Figures

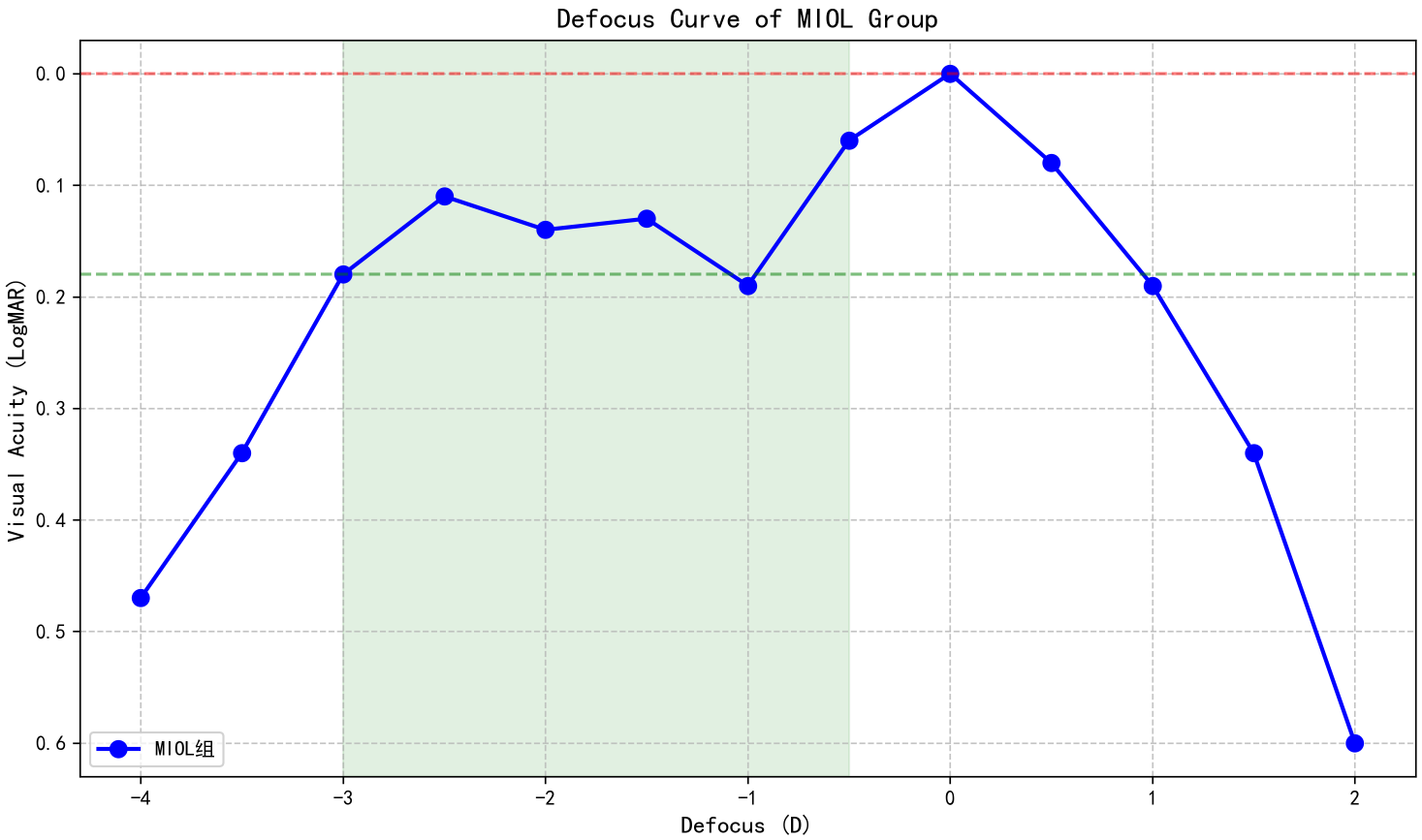


Figure 1

Defocus curve of the MIOL group. The defocus curve demonstrates a distinct "defocus plateau" from 0D to -3D, maintaining visual acuity at LogMAR 0.05-0.18, indicating favorable intermediate and near vision.

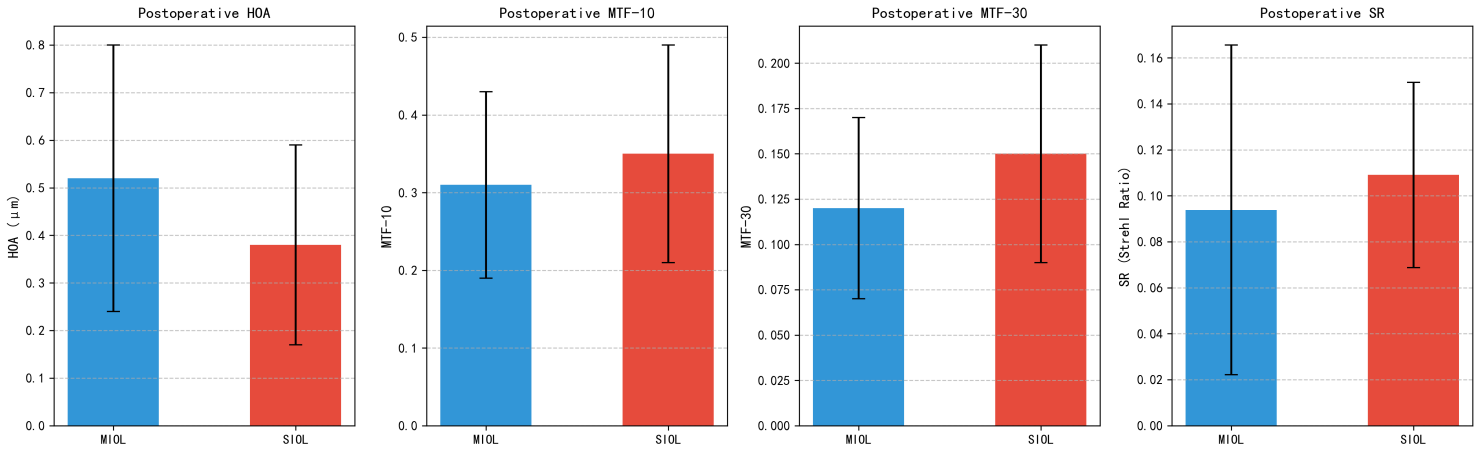


Figure 2

Comparison of postoperative objective visual quality parameters between groups. (A) Higher-order aberration (HOA); (B) MTF-10; (C) MTF-30; (D) Strehl ratio (SR). Error bars represent standard deviation. *P<0.05.

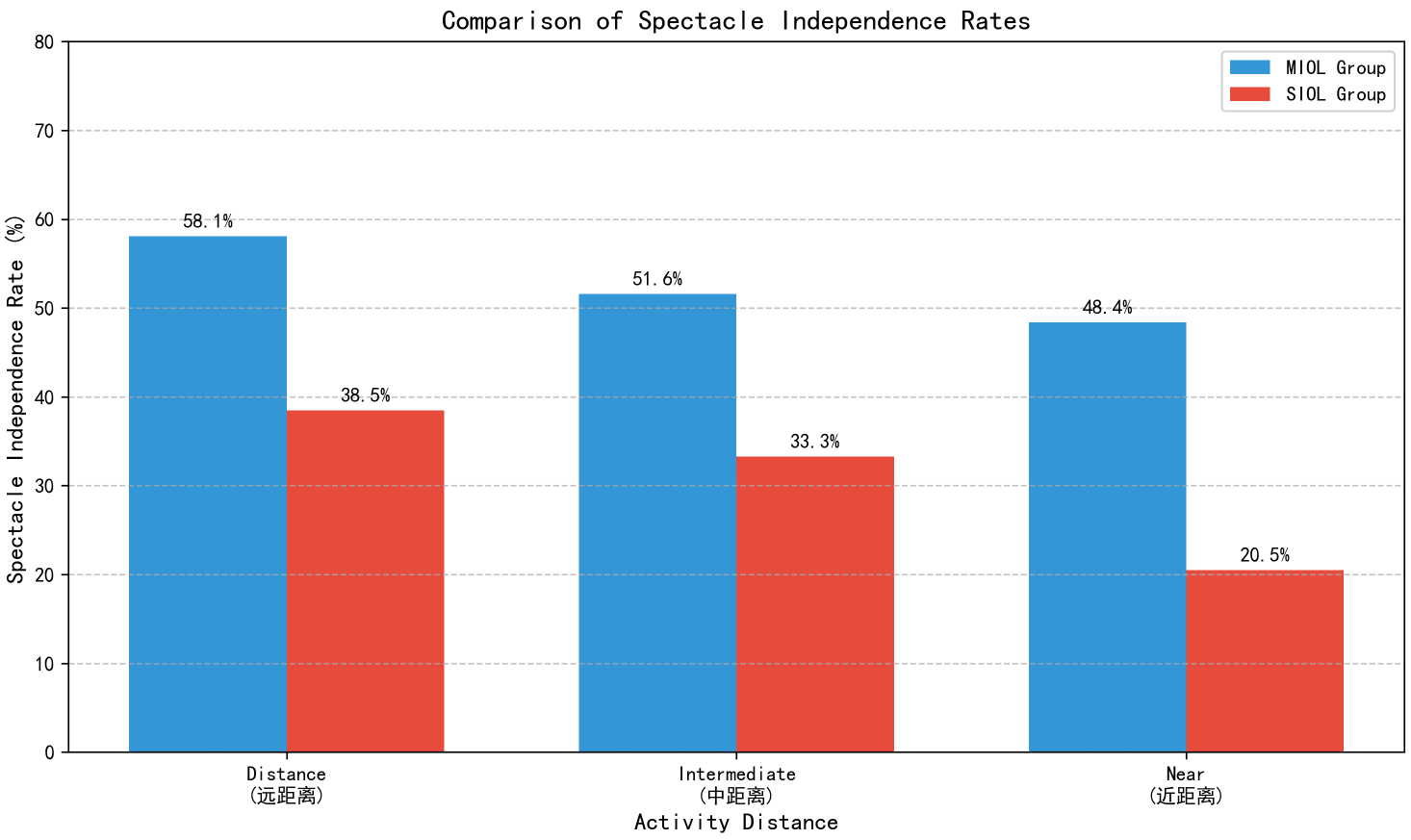


Figure 3

Comparison of spectacle independence rates between groups. The MIOL group demonstrated higher spectacle independence rates across distance, intermediate, and near activities.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryFile1Questionnaire.docx