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Implantation of trifocal intraocular lens in mild pathologic myopia: visual outcomes and influence of fundus structures

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Abstract

Purpose To compare the visual outcomes of simple high myopia (HM) and mild pathologic myopia (PM) following implantation of a trifocal intraocular lens (IOL), and investigate the influence of fundus structures.

Methods We retrospectively studied 63 high myopic eyes of 63 patients underwent femtosecond laser-assisted cataract surgery with implantation of AT LISA tri 839MP IOL (Carl Zeiss Meditec AG, Germany) between July 2020 and September 2024. 34 eyes in the HM group and 29 eyes in the PM group. Main visual outcomes including monocular corrected distance (4 m, CDVA), distance-corrected intermediate (80 cm, DCIVA), distance-corrected near (40 cm, DCNVA) visual acuity, defocus curves, and subjective refraction. Optical coherence tomograph was employed to evaluate macular tilt degree (MTD), central foveal thickness, and subfoveal choroidal thickness. Multiple linear regression analysis was used to evaluate the independent predictors of visual acuity in the PM group.

Results The CDVA, DCIVA, and DCNVA were 0.00 ± 0.00, 0.08 ± 0.05, and 0.09 ± 0.07 logarithm of the minimum angle of resolution (logMAR) in the HM group, 0.02 ± 0.05, 0.15 ± 0.09, and 0.17 ± 0.09 logMAR in the PM group, respectively. In the PM group, mean MTD was 17.13 ± 6.79°. The MTD demonstrated a significant predictive effect on CDVA (regression coefficient: 0.005; $P = 0.026$) and DCNVA (regression coefficient: 0.015; $P = 0.003$).

Conclusion Trifocal IOL implantation yielded favorable visual outcomes in simple high myopic eyes, though results were comparatively poorer in PM cases. MTD was associated with the expected visual outcomes.

Keywords High myopia, pathologic myopia, Trifocal intraocular lens, Visual outcomes

Introduction

Myopia has emerged as a significant global public health concern, particularly with the marked increase in the prevalence of high myopia [1]. High myopia is characterized by excessive and progressive elongation of the eye, leading to biomechanical stretching and thinning of the ocular wall [2]. Simple high myopia (HM) involves axial elongation predominantly in the equatorial region, resulting in scleral backward bowing. This form of myopia is typically not associated with myopic retinal degenerative lesions, except for the presence of tessellated fundus and peripapillary atrophy, and does not significantly impact

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visual acuity (VA) [3, 4]. In contrast, pathologic myopia (PM) is defined by the presence of posterior staphyloma and/or myopic maculopathy equal to or more severe than diffuse chorioretinal atrophy. Notably, 30.8% of patients with pathological myopia exhibit a best-corrected VA worse than 20/60, and pathological staphyloma remains at risk of further progression [3–5].

Individuals with high myopia are more prone to develop cataracts at relatively younger ages and often seek spectacle independence following cataract surgery [6]. However, the relatively poor condition of the fundus, uncertain prognosis, and high expectations for visual outcomes render cataract surgery in highly myopic eyes challenging for both ophthalmologists and patients. Multifocal intraocular lenses (IOLs) are design to provide both near and far distance VA after the cataract surgery, and studies have reported satisfactory visual quality following multifocal IOL implantation in high myopic eyes [7, 8]. The AT LISA tri 839MP IOL is among the most widely utilized trifocal IOLs, recommended as the preferred choice for high-myopic cataracts due to its higher near addition, broader range of IOL power, and ability to provide good visual outcomes [8–11].

While slight structural changes in the ocular wall are difficult to detect using fundus photography or B-scan ultrasonography, optical coherence tomography (OCT) offers the capability to detect imperceptible changes and is widely employed to evaluate the structural characteristics of the eye wall and chorioretinal region [12, 13]. The fundus morphology of highly myopic eyes differs from that of normal eyes, with notable features including reduced choroidal and retinal thickness, and the presence of a tilted macula plane due to scleral backward bowing. The relationship between VA and fundus structural changes in highly myopic eyes with trifocal IOLs remains unclear. In this study, we utilized OCT to assess macular tilt degree (MTD), central foveal thickness (CFT), and subfoveal choroidal thickness (SFCT) to investigate their impact on VA in highly myopic eyes implanted with the AT LISA tri 839MP IOL.

Materials and methods

Study design

We retrospectively analyzed patients who underwent femtosecond laser-assisted cataract surgery with implantation of the AT LISA tri 839 MP IOL (Carl Zeiss Meditec AG, Germany) and a capsular tension ring at Xiamen Eye Center, Xiamen University, between July 2020 and September 2024. This study adhered to the principles of the Declaration of Helsinki, and ethical approval was obtained from the institutional ethics committee. The informed consent was obtained from all of the participants in this study (ChiCTR2200066799). The inclusion criteria were as follows: age > 18 years; axial length (AL) > 26.0 mm; irregular corneal astigmatism < 0.3 μm; and absence of amblyopia, previous ocular surgery, severe myopic retinopathy, glaucoma, intraoperative complications (such as posterior capsular rupture, iris damage, hyphema, zonular dehiscence, etc.) or postoperative complications (such as endophthalmitis, macular edema, IOL dislocation, retinal detachment, etc.).

Patients were thoroughly evaluated using stereoscopic binocular indirect ophthalmoscopy, B-scan ultrasonography (Compact Touch, Quantel Medical, France), and OCT (Heidelberg Engineering, Heidelberg, Germany). According to the classification of myopia by international myopia institute [3], cases presenting with only tessellated fundus and/or peripapillary atrophy, were classified into the simple high myopia group (HM group) (Fig. 1a), and cases presenting with myopic maculopathy no more severe than restricted area around the optic disc diffuse choroidal atrophy were classified into the mild pathologic myopia group (PM group) (Fig. 1c), in accordance with the META-Analysis for Pathologic Myopia classification system (Category 0: no myopic retinal degenerative lesion; Category 1: tessellated fundus; Category 2: diffuse chorioretinal atrophy; Category 3: patchy chorioretinal atrophy; Category 4: macular atrophy.) [14]. In the HM group, we found the cases were along with a flat macula plane, as shown in Fig. 1b. In the PM group, unequal curvature changes were observed in the posterior segment of the eye on OCT imaging, with or without mild posterior staphyloma, accompanied by macular tilt morphology (Fig. 1d).

Preoperative and postoperative examination

The examination included comprehensive biomicroscopy and fundoscopy. Preoperative corrected distance visual acuity (CDVA). Pupil diameter (PD), corneal higher-order aberrations at 4 mm (HOAs), spherical aberration at 6 mm (SA), Chord α and Chord μ were measured by Pentacam (Oculus, Inc.). AL, corneal keratometry (Km), anterior chamber depth (ACD), lens thickness (LT), white-to-white (WTW) and corneal astigmatism were measured by IOLMaster 700 (Carl Zeiss Meditec AG, Inc.).

The postoperative examinations included monocular CDVA and uncorrected distance visual acuity (UDVA) at 4 m, distance-corrected intermediate visual acuity (DCIVA) and uncorrected intermediate visual acuity (UIVA) at 80 cm, distance-corrected near visual acuity (DCNVA) and uncorrected near visual acuity (UNVA) at 40 cm. Monocular defocus curve from + 1.0 D to -4.0 D, in decrements of 0.5 D, were measured with the best distance correction. Subjective refraction was performed at least 1-month post-surgery and evaluated spherical equivalent (SE). The near, intermediate and far distance VA were evaluated using an Early Treatment Diabetic

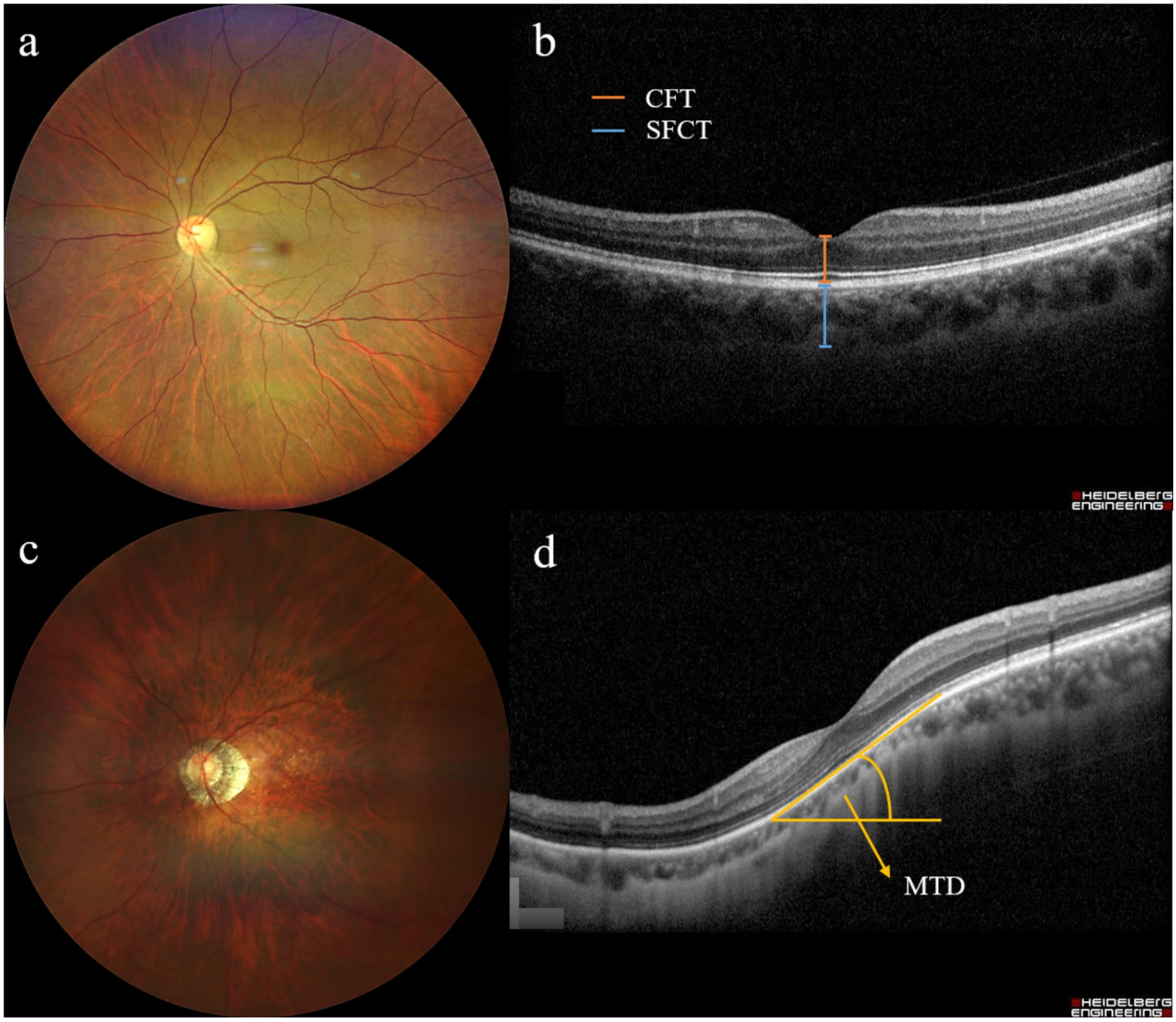

Fig. 1 The fundus images and OCT scanning image of macula area. Tessellated fundus and flat macula plane in simple high myopia (**a, b**). Restricted area around the optic disc diffuse choroidal atrophy and tilted macula plane in mild pathologic myopia (**c, d**)

Retinopathy Study chart (Wehen Vision Technology Co. Ltd, Guangzhou, China) under 85 cd/m^2.

Evaluation of fundus

Patients were examined using Spectral Domain OCT (Heidelberg Engineering, Heidelberg, Germany), with 12 radial scans centered on the 6-mm central macular area, postoperatively. Macular plane tilt was defined as the steep angle of inclination between the macula and the optic disc observed in the OCT image. Horizontal and vertical sections passing through the center of the fovea were selected for analysis. ImageJ software was employed to measure the MTD and calculate the average tilt angle (Fig. 1d). This MTD measurement method was referred to the study by Alfonso-Bartolozzi et al. [15]. The SFCT was measured as the perpendicular distance from the outer edge of the hyperreflective line corresponding to the retinal pigment epithelium (automatically detected by the instrument) to the hyporeflective line or margin representing the choroid-scleral interface, which was manually delineated by an experienced grader. CFT was also measured (Fig. 1b).

Surgical technique and intraocular lens

Femtosecond laser-assisted cataract surgery was performed using the LenSx® laser system (Alcon, Fort Worth, TX, USA), it was utilized for anterior capsulotomy and nuclear fragmentation, the target capsulotomy diameter was 5.2 mm. A standardized phacoemulsification was performed by a senior and experienced surgeon (G.Z.) through a 2.2 mm temporal clear corneal incision using the Centurion active-fluidics System (Alcon

Laboratories, Inc.). The IOL and capsular tension ring were implanted in all cases. After surgery, all patients received the same treatment consisting of a combination of levofloxacin (Cravit) and dexamethasone (Tobradex) eye drops 4 times a day during the first week, and then gradually tapered over the following three weeks.

IOL power was calculated using the Barrett Universal II (BUII) formula, and the lens factor of 1.83 was used. We selecting the IOL power that yielded a target refraction closest to 0 D for eyes with AL between 26.0 and 28.0 mm, the first available negative-power IOL for eyes with AL between 28.0 and 30.0 mm, and choose the target refraction close to -0.50 D with AL exceeding 30.0 mm.

The AT LISA tri 839MP (Carl Zeiss Meditec AG, Inc.) is a single-piece, aspheric (-0.18 asphericity), diffractive trifocal lens. It features a 6.0 mm optic with a central trifocal zone extending over a 4.34 mm diameter and a peripheral bifocal zone from 4.34 to 6.0 mm. The light distribution is allocated as 50% for distance, 20% for intermediate, and 30% for near focus. The lens provides + 3.33 D addition for near vision and + 1.66 D for intermediate vision at the IOL plane. IOL power ranges from 0.00 to + 32.00 D in 0.50 D increments [16].

Table 1 Baseline characteristics

Parameter	Overall (*n* = 63)	HM Group (*n* = 34)	PM Group (*n* = 29)	*P* value†
Age (y)	55.24 ± 6.32	55.75 ± 7.85	54.67 ± 4.17	0.942
AL (mm)	27.59 ± 1.25	27.20 ± 0.98	28.05 ± 1.39	0.016*
Km (D)	42.79 ± 1.43	43.02 ± 1.52	42.51 ± 1.28	0.150
TCA (D)	0.47 ± 0.23	0.48 ± 0.24	0.46 ± 0.22	0.654
ACD (mm)	3.45 ± 0.35	3.46 ± 0.35	3.44 ± 0.36	0.836
LT (mm)	4.23 ± 0.32	4.29 ± 0.36	4.17 ± 0.27	0.348
CCT (mm)	541.68±36.02	530.47±34.88	554.83±33.26	0.006*
WTW (mm)	11.97 ± 0.48	12.05 ± 0.38	11.87 ± 0.56	0.150
PD (mm)	2.96 ± 0.49	3.07 ± 0.54	2.83 ± 0.41	0.166
HOAs (μm)	0.17 ± 0.09	0.17 ± 0.08	0.17 ± 0.10	0.912
SA (μm)	0.26 ± 0.13	0.27 ± 0.12	0.25 ± 0.15	0.820
Chord α (mm)	0.27 ± 0.14	0.25 ± 0.13	0.28 ± 0.15	0.495
Chord μ (mm)	0.21 ± 0.12	0.19 ± 0.11	0.23 ± 0.14	0.362
IOL power (D)	10.30 ± 3.26	10.88 ± 3.26	9.62 ± 3.18	0.127
Target refraction (D)	-0.12 ± 0.13	-0.09 ± 0.12	-0.15 ± 0.14	0.078
CDVA (logMAR)	0.69 ± 0.41	0.70 ± 0.39	0.67 ± 0.45	0.608
CFT (μm)	208.08±22.89	206.39±18.06	210.07±27.73	0.529
SFCT (μm)	139.14±71.81	163.61±77.92	110.45±51.81	0.003*

HM Group = simple high myopia group; PM Group = mild pathologic myopia group. ACD = anterior chamber depth; AL = axial length; CCT = central corneal thickness; CDVA = corrected distance visual acuity; CFT = central foveal thickness; D = diopter; HOAs = corneal higher-order aberrations; IOL = intraocular lens; Km = corneal keratometry; logMAR = logarithm of the minimum angle of resolution; LT = lens thickness; PD = pupil diameter; SA = spherical aberration; SFCT = subfoveal choroidal thickness; TCA = total corneal astigmatism; WTW = white-to-white

†Comparison between the HM and PM groups

*Statistically significant ($P < 0.05$)

Statistical analysis

Statistical analysis was conducted using SPSS for Windows software (version 26.0, IBM Corp). The normality of the variables was assessed using the Shapiro-Wilk test. Variables that followed a normal distribution were compared between the two groups using the independent-samples t-test, while non-normally distributed variables were compared using the Mann-Whitney U test. Multiple linear regression analysis was used to examine the independent predictor of postoperative VA. Correlation analysis is conducted to preliminarily explore the relationships between each explanatory variable and the response variable. Multiple linear regression model is introduced to assess the independent contributions of each variable, utilizing metrics such as regression coefficients, t-values, and R-squared to evaluate the model's goodness of fit and predictive accuracy. A *P* value of less than 0.05 was considered statistically significant.

Results

This study enrolled 63 eyes of 63 patients, the mean age of the patients was 55.24 ± 6.32 years, 39 males and 24 females. The mean follow-up time was 3.57 ± 2.89 months. 34 eyes were enrolled in the HM group (Category 0: 6 eyes; Category 1: 28 eyes), 29 eyes were enrolled in the PM group (all Category 2). Baseline characteristics were shown in Table 1.

Visual acuity and postoperative refraction

The CDVA was 0.00 ± 0.00 and 0.02 ± 0.05 logarithm of the minimum angle of resolution (logMAR) for the HM and PM groups, respectively, with the HM group showing significantly better outcomes ($P = 0.006$). The UDVA was 0.04 ± 0.07 and 0.07 ± 0.11 logMAR for the HM and PM groups, respectively, with no significant difference between the groups ($P = 0.577$). The DCIVA and UIVA was 0.08 ± 0.05 and 0.10 ± 0.07 logMAR in the HM group, respectively, 0.15 ± 0.09 and 0.16 ± 0.10 logMAR in the PM group, respectively, the HM group showing significantly better outcomes (DCIVA: $P < 0.001$; UIVA: $P = 0.003$). The DCNVA and UNVA was 0.09 ± 0.07 and 0.12 ± 0.10 logMAR in the HM group, respectively, 0.17 ± 0.09 and 0.20 ±0.11 logMAR in the PM group, respectively, the HM group showing significantly better outcomes (DCNVA: $P < 0.001$; UNVA: $P = 0.001$) (Table 2).

In the HM and PM groups, about 60% of eyes achieved UDVA of 20/20 (61.8% and 58.6%, respectively), and nearly 90% of eyes achieved UDVA of 20/25 (88.2% and 86.2% eyes, respectively). However, the cumulative percentage of eyes with CDVA of 20/20 was lower in the PM group (79.3%) than in the HM group (100%). The

Table 2 Visual outcomes of the HM and PM groups

	HM Group	PM Group	*P* value
UDVA (logMAR)			
Mean ± SD	0.04 ± 0.07	0.07 ± 0.11	0.577
Range	0.00 to 0.30	0.00 to 0.40	
CDVA (logMAR)			
Mean ± SD	0.00 ± 0.00	0.02 ± 0.05	0.006*
Range	0.00 to 0.00	0.00 to 0.20	
UIVA (logMAR)			
Mean ± SD	0.10 ± 0.07	0.16 ± 0.10	0.003*
Range	0.00 to 0.20	0.00 to 0.40	
DCIVA (logMAR)			
Mean ± SD	0.08 ± 0.05	0.15 ± 0.09	< 0.001*
Range	0.00 to 0.20	0.00 to 0.40	
UNVA (logMAR)			
Mean ± SD	0.12 ± 0.10	0.20 ±0.11	0.001*
Range	0.00 to 0.40	0.00 to 0.40	
DCNVA (logMAR)			
Mean ± SD	0.09 ± 0.07	0.17 ± 0.09	< 0.001*
Range	0.00 to 0.30	0.00 to 0.40	
SE (D)			
Mean ± SD	-0.07 ± 0.26	-0.13 ± 0.24	0.251
Range	-0.75 to 0.50	-0.75 to 0.50	

HM Group = simple high myopia group; PM Group = mild pathologic myopia group. CDVA = corrected distance visual acuity; D = diopters; DCIVA = distance-corrected intermediate visual acuity; DCNVA = distance-corrected near visual acuity; logMAR = logarithm of the minimum angle of resolution; SD = standard deviation; SE = spherical equivalent; UDVA = uncorrected distance visual acuity; UIVA = uncorrected intermediate visual acuity; UNVA = uncorrected near visual acuity

*Statistically significant ($P < 0.05$)

cumulative percentage of eyes with UIVA and UNVA of 20/25 or better was lower in the PM group (51.7% and 44.8%, respectively) than in the HM group (79.4% and 73.5%, respectively). The cumulative percentage of eyes with DCIVA and DCNVA of 20/25 or better was lower in the PM group (55.2% and 48.3%, respectively) than in the HM group (94.1% and 88.2%, respectively) (Fig. 2).

The postoperative SE was − 0.07 ± 0.26 in the HM group and − 0.13 ± 0.24 D in the PM group ($P = 0.251$). In the HM groups, 88.3% of eyes had UDVA within one line of CDVA, 100% of eyes within ±0.50 D of prediction error, and 79.5% of eyes had postoperative refractive cylinder within 0.50 D. In the PM groups, 86.2% of eyes had UDVA within one line of CDVA, 93.0% of eyes within ±0.50 D of prediction error, and 86.2% of eyes had postoperative refractive cylinder within 0.50 D (Fig. 3).

Defocus curve

The defocus curves for the HM and PM groups are shown in Fig. 4. VA in the HM group was consistently superior across all defocus points compared to the PM group. At vergence of -0.5 D, -1.0 D, -1.5 D, -2.0 D and − 2.5 D, the HM group exhibited significantly better VA than the PM group ($P = 0.002$, $P < 0.001$, $P = 0.003$, $P < 0.001$, and $P = 0.032$, respectively). The defocus curve for the HM group demonstrated a broad landing area, maintaining a mean visual acuity of 0.20 logMAR or better within the + 0.5 D to -3.0 D range. In contrast, the PM group's defocus curve displayed a bimodal pattern, with visual acuity declining sharply beyond − 0.5 D and a small peak occurring at -3.0 D vergence.

Independent predictor of visual acuity in pathologic myopia

To analyze the independent predictive effects of multiple independent variables on CDVA, DCIVA, and DCNVA, we conducted multiple linear regression analyses for each dependent variable separately, and the results are shown in Table 3. In the PM group, mean MTD was 17.13 ± 6.79°.

In terms of CDVA, the F-statistics value was 2.162, the overall fit of the model was not significant ($P = 0.107$). However, the R^2 value of 0.796 suggests that the independent variables accounted for 79.6% of the variation in CDVA. The MTD had a significant predictive effect on CDVA ($P = 0.026$). The regression coefficient for MTD was 0.005, indicating that for 1° increase in MTD, the CDVA increased by 0.005 logMAR.

In terms of DCIVA, the F-statistics value was 2.987, the overall fit of the model was significant ($P = 0.041$), with an R^2 value of 0.843, indicating that the independent variables explained 84.3% of the variation in DCIVA. Age ($P = 0.050$), SFCT ($P = 0.050$), and Chord μ ($P = 0.037$) were found to have significant predictive effects on DCIVA. The regression coefficient for SFCT was − 0.001, suggesting that for 1 μm decrease in SFCT, the DCIVA increased by 0.001 logMAR. The regression coefficient for age and Chord μ was 0.012 and 0.328, respectively.

In terms of DCNVA, the F-statistics value was 1.671, the overall fit of the model was not significant ($P = 0.205$). However, the R^2 value of 0.750 suggests that the independent variables accounted for 75.0% of the variation in DCNVA. The MTD demonstrated a significant predictive effect on DCNVA ($P = 0.003$), with a regression coefficient of 0.015, implying that for 1° increase in MTD, the DCNVA increased by 0.015 logMAR.

Discussion

PM usually have posterior staphyloma and/or myopic maculopathy, thus at risk of reducing visual performance [3]. It should be cautious that contrast sensitivity after multifocal IOLs implantation was decreased, and patients with poor fundus conditions maynot obtain satisfactory vision [17]. We demonstrated that the visual outcomes of mild pathologic myopia eyes implanted with trifocal IOL were worse than simple high myopia eyes, especially in near and intermediate VA. The MTD caused

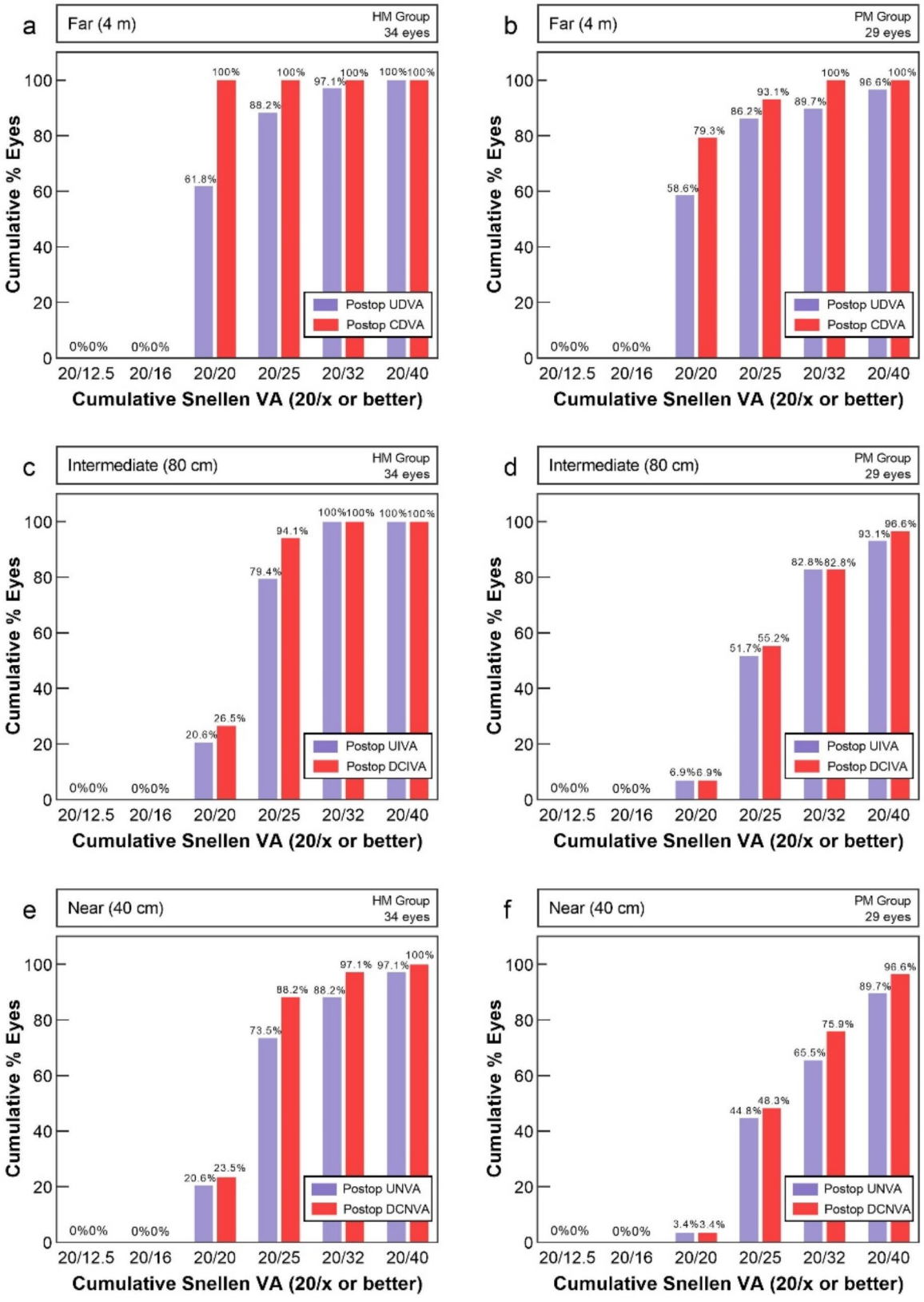

Fig. 2 Cumulative percentage of eyes achieving monocular corrected and uncorrected visual acuity at far (**a, b**), intermediate (**c, d**), and near distance (**e, f**). HM group = simple high myopia group; PM group = mild pathologic myopia group; CDVA = corrected distance visual acuity; DCIVA = distance-corrected intermediate visual acuity; DCNVA = distance-corrected near visual acuity; UDVA = uncorrected distance visual acuity; UIVA = uncorrected intermediate visual acuity; UNVA = uncorrected near visual acuity

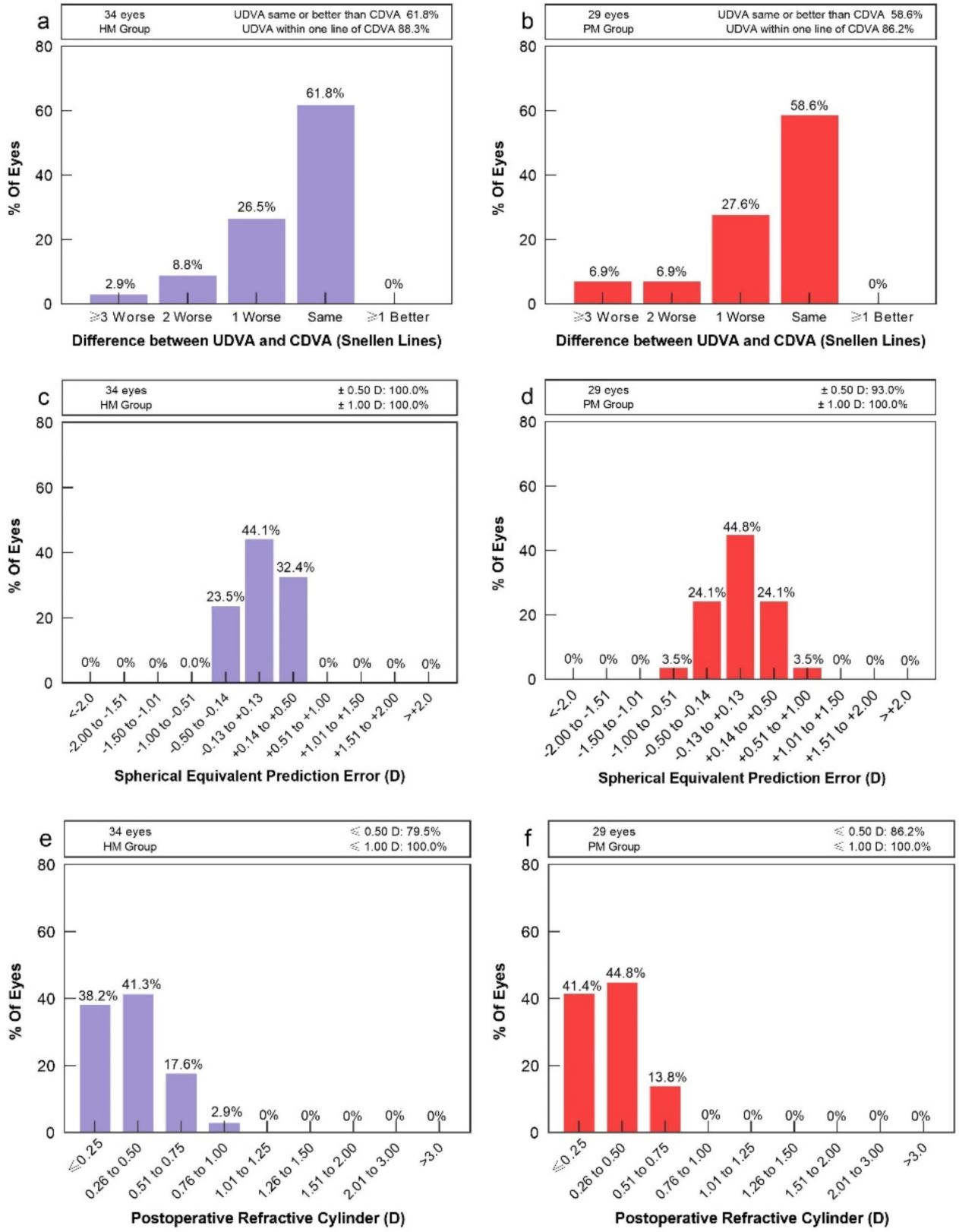

Fig. 3 (**a, b**) Difference on lines in far distance between postoperative UDVA and CDVA. (**c, d**) Spherical equivalent prediction error distribution. (**e, f**) Postoperative refractive cylinder distribution. HM group = simple high myopia group; PM group = mild pathologic myopia group; CDVA = corrected distance visual acuity; UDVA = uncorrected distance visual acuity; D = diopter

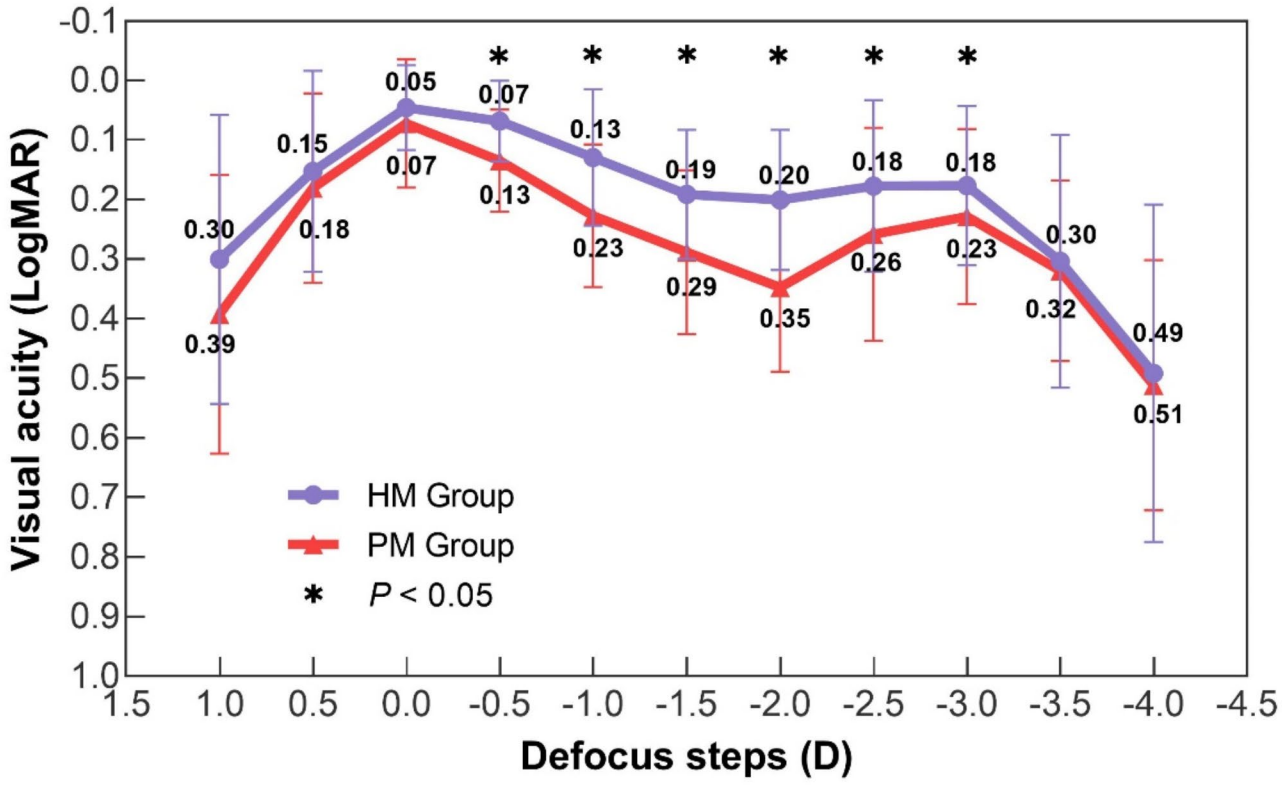

Fig. 4 Defocus curves of the HM group and PM group. HM group = simple high myopia group; PM group = mild pathologic myopia group; logMAR = logarithm of the minimum angle of resolution; D = diopter. *statistically significant difference between two groups

by unequal elongation of the posterior segment of the eye was related with expected VA.

In terms of cumulative VA, 100% of eyes in the HM group achieved a CDVA of 20/20, compared to only 79.3% in the PM group. Additionally, in the HM group, DCIVA and DCNVA of 20/25 or better were achieved in 94.1% and 88.2% of cases, respectively, while these percentages were significantly lower in the PM group at 55.2% and 48.3%, respectively. When comparing defocus curves, the HM group demonstrated superior VA across all vergence levels (+ 1.0 D to -4.0 D, in decrements of 0.5 D), achieving a depth of focus of approximately 3.5 D (with a threshold VA of 0.2 logMAR). As reported by Alfonso-Bartolozzi et al., high myopic patients without posterior staphyloma who received trifocal IOLs exhibited significantly better VA compared to those with nasal-inferior staphyloma [15].

In the PM group, although eyes achieved good distance VA, the intermediate and near vision reduced significantly. Notably, the advantage of intermediate foci was not observed on the defocus curve in the PM group, the bimodal shape of curve is similar as performance of bifocal IOLs, indicating the intermediate focus of this type of trifocal IOL cannot provide satisfactory intermediate vision in patients with myopic retinopathy. When compared with our previous reported study [18], VA of the HM group was nearly equivalent to that of normal eyes implanted with the AT LISA tri 839MP IOL, indicating that simple high myopic eyes can achieve a good whole range of vision following trifocal IOL implantation.

Accurate IOL power calculation in eyes with high myopia (axial length ≥ 26.0 mm) has historically been challenging [19]. However, the development of new-generation IOL calculation formulas have significantly improved the prediction accuracy in highly myopic eyes, making visual outcomes after trifocal IOL implantation more predictable and successful [20, 21]. Abulafia et al. reported that the BUII formula achieves good prediction accuracy in low-powered IOLs for highly and extremely myopic eyes [19], while Rong et al. demonstrated the high accuracy of BUII, with a median absolute prediction error of 0.37 D and 70.0% of eyes within ± 0.5 D of the predicted error [22]. In our study, IOL power was calculated using the IOLMaster 700 and the BUII formula, 100% of eyes in the HM group and 93% of eyes in the PM group achieved prediction error within ± 0.5 D.

To investigate the fundus factors influencing VA in pathologic myopic eyes implanted with the AT LISA tri 839MP IOL, we constructed a multiple linear regression model to explore the impact of fundus structure on postoperative VA among multiple factors. In the PM group, the MTD was independent predictor for CDVA

Table 3 Outcomes of multiple linear regression model in the PM group

	Regression Coefficient	Standard Error	t	*P* value
Response variable: CDVA ($F = 2.162$; $R^2 = 0.796$; $P = 0.107$)				
Const	-13.126	5.842	-2.247	0.048
IOL power	0.095	0.047	2.027	0.070
Age	-0.002	0.004	-0.475	0.645
MTD	0.005	0.002	2.615	0.026*
CFT	0.000	0.000	0.471	0.648
SFCT	0.000	0.000	1.117	0.290
AL	0.222	0.108	2.052	0.067
ACD	-0.116	0.069	-1.693	0.121
LT	0.068	0.065	1.050	0.318
WTW	0.015	0.034	0.443	0.667
Km	0.136	0.063	2.160	0.056
TCA	-0.026	0.043	-0.603	0.560
CCT	0.000	0.000	0.241	0.814
Chord μ	0.039	0.086	0.458	0.657
Chord α	-0.140	0.129	-1.081	0.305
HOAs	0.056	0.140	0.405	0.694
SA	-0.063	0.061	-1.036	0.325
PD	0.029	0.031	0.947	0.366
Preoperative CDVA	0.076	0.074	1.030	0.327
Response variable: DCIVA ($F = 2.987$; $R^2 = 0.843$; $P = 0.041$)				
Const	5.029	9.307	0.540	0.601
IOL power	-0.061	0.075	-0.816	0.434
Age	0.012	0.006	2.231	0.050*
MTD	0.005	0.003	1.668	0.126
CFT	0.001	0.001	1.445	0.179
SFCT	-0.001	0.000	-2.225	0.050*
AL	-0.173	0.172	-1.006	0.338
ACD	0.073	0.109	0.665	0.521
LT	0.130	0.104	1.255	0.238
WTW	0.037	0.053	0.698	0.501
Km	-0.047	0.100	-0.471	0.648
TCA	-0.019	0.068	-0.284	0.783
CCT	0.000	0.001	0.456	0.658
Chord μ	0.328	0.137	2.400	0.037*
Chord α	0.279	0.206	1.356	0.205
HOAs	0.185	0.222	0.833	0.424
SA	-0.137	0.097	-1.421	0.186
PD	0.074	0.050	1.497	0.165
Preoperative CDVA	-0.083	0.117	-0.705	0.497
Response variable: DCNVA ($F = 1.671$; $R^2 = 0.750$; $P = 0.205$)				
Const	4.231	11.718	0.361	0.726
IOL power	-0.064	0.094	-0.678	0.513
Age	0.009	0.007	1.283	0.229
MTD	0.015	0.004	3.838	0.003*
CFT	-0.001	0.001	-0.711	0.493
SFCT	-0.001	0.001	-2.151	0.057
AL	-0.164	0.217	-0.756	0.467
ACD	0.132	0.138	0.961	0.359
LT	-0.046	0.130	-0.350	0.734
WTW	0.063	0.067	0.939	0.370
Km	-0.030	0.126	-0.240	0.816
TCA	-0.007	0.086	-0.083	0.935

Table 3 (continued)

	Regression Coefficient	Standard Error	t	*P* value
CCT	0.001	0.001	1.874	0.090
Chord μ	0.190	0.172	1.106	0.295
Chord α	0.237	0.259	0.914	0.382
HOAs	0.333	0.280	1.188	0.262
SA	-0.104	0.122	-0.859	0.410
PD	0.045	0.062	0.724	0.485
Preoperative CDVA	-0.221	0.148	-1.496	0.165

ACD = anterior chamber depth; AL = axial length; CCT = central corneal thickness; CDVA = corrected distance visual acuity; CFT = central foveal thickness; HOAs = corneal higher-order aberrations; IOL = intraocular lens; Km = corneal keratometry; LT = lens thickness; PD = pupil diameter; SA = spherical aberration; SFCT = subfoveal choroidal thickness; TCA = total corneal astigmatism; WTW = white-to-white

*Statistically significant ($P < 0.05$)

and DCNVA, and larger MTD values are associated with poorer visual outcomes. This phenomenon may be attributed to the steep macular tilt caused by unequal elongation of the posterior portion of the eye, pathologic myopic retinopathy would result in visual impairment and reduced retinal sensitivity [23, 24]. OCT examination is crucial for prognosis evaluation in highly myopic eye before cataract surgery [25].

The SFCT was found to be an independent predictor for DCIVA in the PM group, and a thinner SFCT was associated with worse DCIVA. The reduced SFCT may impair photoreceptor metabolism, potentially leading to decreased VA [26]. In highly myopic eyes, retinal sensitivity is associated with SFCT [24], and a thin SFCT has been identified as a risk factor for low vision following cataract surgery [27]. Given that the AT LISA tri 839MP lens distributes 50%, 20%, and 30% of light to the distance, intermediate, and near focus, respectively, the low energy distribution of intermediate foci may be more sensitive to changes of SFCT. We proposed that the intermediate vision is specifically poor among other distance was due to this reason. We did not find a significant effect of CFT on postoperative vision, consistent with previous findings [24].

Previous studies have reported that the CFT and SFCT in a normal Chinese adult population are 237.38 ± 23.05 μm and 261.2 ± 110.5 μm, respectively [28, 29]. In our study, the corresponding measurements were 208.08 ± 22.89 μm and 139.14 ± 71.81 μm, indicating a significant thinning compared to normal eyes. Despite the relatively poor fundus condition in highly myopic eyes, most patients can still achieve good postoperative vision. He et al. analyzed the visual outcomes of 2,027 highly myopic eyes after cataract surgery and found that 66.8% achieved VA between 20/40 and 20/20, with better visual prognosis in patients without pathological myopia [27]. Eyes in the HM and PM groups exhibited good distance VA, this may be due to the absence of severe myopic retinopathy in our patient cohort, allowing for normal far vision despite the relatively thinner CFT and SFCT.

This study has several limitations. First, we did not analyze the types of posterior staphyloma. In many cases, staphyloid changes in the posterior eye wall are subtle, and the edges of staphyloma do not show clear pigmentary alterations in photographs. Additionally, the scan length of OCT is often insufficient to reveal the entire extent of the staphyloma. Second, this retrospective study lacks functional retinal measurements, such as microperimetry, which are not routinely performed. Third, as a cross-sectional study, it does not capture the progression of disease over time. A longitudinal study would provide more insight into these findings.

In conclusion, trifocal IOLs provide a good range of vision in highly myopic eyes. The acceptable results may be achieved in eyes with mild myopic chorioretinopathy, but visual outcomes generally are poorer compared to simple high myopia. The unequal elongation of the posterior eye wall can cause structural changes in the macular region, and a thorough preoperative evaluation using OCT is crucial for achieving favorable prognoses.

Abbreviations

ACD	Anterior chamber depth
AL	Axial length
BUII	Barrett Universal II
CDVA	Corrected distance visual acuity
CFT	Central foveal thickness
D	Diopter
HM	High myopia
HOAs	Corneal higher-order aberrations
IOLs	Intraocular lenses
Km	Corneal keratometry
logMAR	Logarithm of the minimum angle of resolution
LT	Lens thickness
MTD	Macular tilt degree
OCT	Optical coherence tomography
PD	Pupil diameter
PM	Pathologic myopia
SA	Spherical aberration
SE	Spherical equivalent
SFCT	Subfoveal choroidal thickness
TCA	Total corneal astigmatism
UDVA	Uncorrected distance visual acuity
UIVA	Uncorrected intermediate visual acuity
UNVA	Uncorrected near visual acuity
VA	Visual acuity
WTW	White-to-white

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Author contributions
Meiyi Zhu: Conceptualization, Methodology, Validation, Formal Analysis, Investigation, Data Curation, Writing-Original Draft, Writing-Review & Editing; Zongsheng Zeng: Methodology, Validation, Investigation; Wei Fan: Methodology, Investigation; Guangbin Zhang: Supervision, Project administration, Funding support.

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Data availability
The data presented in this study are included in the article. The data are not publicly available due to restrictions that apply to the availability of the data (e.g., privacy or ethical). Datasets from this study may be available upon request from the corresponding author and provided upon approval from the sponsor and in accordance with data privacy and ethical provisions.

Declarations

Ethics approval and consent to participate
This study involving human participants were reviewed and approved by the Human Ethics Committee of Xiamen University affiliated with the Xiamen Eye Center. The informed consent was obtained from all of the participants in this study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Conflict of interest
No conflicting relationship exists for any author.

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