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RESEARCH

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Characteristics of biological parameters and implantable collamer lens (ICL) size selection in moderate, high, and super-high myopia eyes

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Abstract

Objective To analyze the characteristics of anterior segment biometric parameters in moderate, high, and super-high myopia eyes for ICL size selection.

Methods A total of 246 eyes of 131 patients were included in this prospective observational cohort study. Preoperative axis length (AL), central keratometry (Kc), central corneal thickness (CCT), white-to-white (WTW), internal anterior chamber depth (ACD), trabecular iris angle (TIA), anterior chamber width (ACW), angle-to-angle distance (ATA), crystalline lens rise (CLR), lens thickness (LT), sulcus-to-sulcus (STS), ICL size, and postoperative vault at 1 month were recorded and compared among the different degrees of myopia groups.

Results The moderate myopia showed smaller ACD and TIA than high and super-high myopia ($P<0.05$). A higher proportion of CLR positive (+) was in the moderate myopia group (65%), while the super-high myopia group had a higher proportion of CLR negative (-) (55.3%). ($P=0.047$). There were no statistical differences among the myopia groups in WTW, ATA, ACW, STS, LT, and postoperative vault ($P>0.05$). In different degrees of myopia groups, vertical ATA, ACW and STS were longer than horizontal ATA, ACW and STS ($P<0.001$), and horizontal-STS showed a higher correlation with horizontal-ATA ($r=0.655$) and horizontal-ACW ($r=0.660$) than with WTW ($r=0.591$). The 12.1 mm size ICL was slightly selected in moderate myopia (35.8%) more than high myopia (14.6%) and super-high myopia (26.3%) ($P=0.013$).

Conclusion Compared to high and super-high myopia, moderate myopic eyes exhibited smaller ACD, TIA while similar WTW, ATA, ACW and STS, with the lens positioned more anteriorly. It should be concerned to the effect of sagittal axis parameters ACD and CLR on the ICL size in different degrees of myopia.

Keywords Posterior chamber intraocular lens implantation, Myopia, Anterior chamber parameters, ICL size

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Introduction

Implantable collamer lens (ICL) implantation is a type of refractive correction surgery that involves implanting an artificial lens, specifically a posterior chamber phakic intraocular lens (pIOL). More than 2 million ICLs have been implanted worldwide [1]. EVO ICL (ICL-V4c, STAAR Surgical Co., Nidau, Switzerland) was first introduced in 2011. Compared to the previous version of Visian ICL (V4), the EVO ICL has a central hole (approximately 360 μm in diameter) in the center of the optic. This hole ensures aqueous humor flow, eliminating the need for laser peripheral iridotomy, thus reducing postoperative complications like elevated intraocular pressure and enhancing surgical safety. Studies have confirmed that implantation of the EVO ICLs is safe, effective, and provides stable refractive outcomes with low rate of adverse events [2–4]. It has been reported EVO ICLs could offer better visual quality compared to LASIK, PRK, and SMILE [5]. Unlike laser refractive surgeries that alter the cornea, ICL implantation preserves corneal morphology and biomechanics, providing a larger effective optical zone on the cornea and inducing fewer higher-order aberrations, resulting in superior postoperative visual quality [6–7]. Consequently, ICL implantation has become a popular method for myopia correction.

ICL implantation covers a broad range of refractive errors (-0.5 to -18.0D), catering to patients with low to extremely high myopia. Research has shown that implantation of EVO ICL is safe, effective, and predictable in correcting high and super-high myopia [8]. The overall postoperative corrected distance visual acuity improvement gap in super-high myopic patients was larger than in high myopic patients [9]. An increasing number of patients with low to moderate myopia are concerned about ICL implantation [10]. Several short-term studies have reported the predictability and visual outcomes of ICL implantation for low to moderate myopia (below −6.00D) are comparable to high myopic patient outcomes [11, 12]. EVO ICL implantation can be considered a viable surgical option for correcting low and moderate myopia, especially in cases where corneal refractive surgery is not recommended [13, 14]. However, the earlier reports primarily focused on ICL predicting vault, safety, and visual quality [15–17], few studies conducted on the specificities and differences in anterior segment biometric parameters and their implications for ICL size in different degrees of myopia. It is still uncertain whether the lower the refractive error, the smaller the anterior segment space. Therefore, this paper aims to compare and analyze the anterior segment biometric data of individuals with different levels of myopia, hoping to improve the selection of the suitable ICL size, optimize its positioning, and obtain the optimal vault.

Materials and methods

Study design

This prospective observational cohort study adhered to the principles of the Helsinki Declaration and received ethical approval from the Ethics Committee of Tianjin Medical University Eye Hospital (No.2021KY(L)-18). The study included 131 patients (246 eyes) who underwent ICL implantation at Tianjin Medical University Eye Hospital between September 2021 and December 2022. All patients received routine examinations and met the criteria for ICL implantation. Inclusion criteria were as follows: age 18–50 years, stable refraction, spherical refractive error between −3.00D and −20.00D, astigmatism less than −5.00D, anterior chamber depth (ACD: distance from corneal endothelium to anterior surface of the lens) > 2.8 mm, and endothelial cell count > 2000 cells/mm². Exclusion criteria included corneal scars, corneal ectasia, corneal dystrophy, high intraocular pressure, glaucoma, iris cysts, lens opacity, and previous ocular surgeries.

Preoperative assessment and grouping

Before surgery, all patients underwent ophthalmic examinations, including visual acuity, objective refraction, objective refraction after cycloplegia, and corrected visual acuity. IOP was assessed using a non-contact tonometer (NCT, TX-20 Full Auto Tonometers, Canon, Japan), and anterior segment structures were evaluated with a slit-lamp, followed by a dilated fundus examination. The Pentacam (Pentacam HR, OCULUS Optikgeräte GmbH, Wetzlar, Germany) was used to measure WTW, CCT, Kc. Anterior segment optical coherence tomography (AS-OCT, CASIA-2, TOMEY, Japan) was used to measure anterior chamber depth (ACD), angle-to-angle distance (ATA), anterior chamber width (ACW), crystalline lens rise (CLR), trabecular iris angle (TIA-500). ACD, TIA, and CLR were recorded at the horizontal meridian, while ATA and ACW were recorded at both horizontal and vertical meridians. ATA is the distance between anterior chamber angles along the horizontal (or vertical) meridian, and ACW is the distance between scleral spurs along the horizontal (or vertical) meridian. (Fig. 1) CLR is the distance between the anterior apex of the lens and the ATA line, with positive values (+) for the lens apex anterior to the ATA line and negative values (-) for the posterior. TIA-500 was defined as the trabecular iris angle at 500 μm from the scleral spur, and average values at the nasal and temporal angles were used for statistical analysis. Axis length (AL) was measured using the Lenstar-900 (LS-900, Haag Streit AG, Switzerland), and UBM (MEDA-300 L, China) was utilized to measure sulcus-to-sulcus (STS) and assess ciliary body morphology and cysts. STS refers to the distance between the ciliary sulci in the same meridian direction, measured and

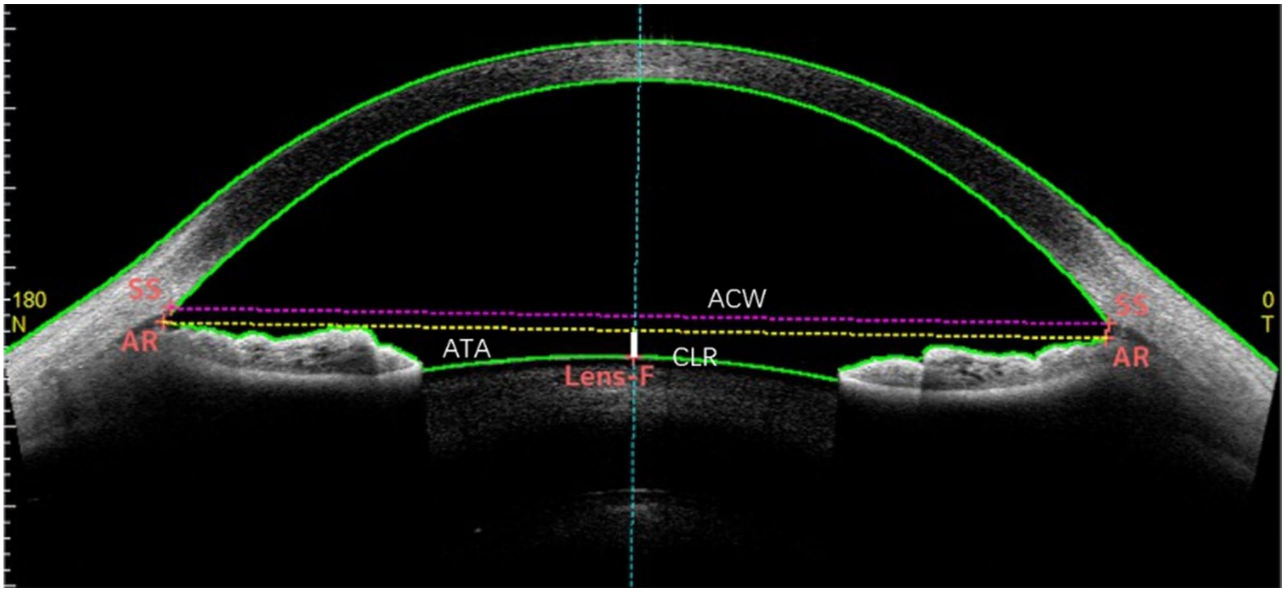

Fig. 1 Measurement parameters with optical coherence tomography (OCT). The distance between anterior chamber angles (AR-AR) is angle-to-angle (ATA) diameter. The distance from the anterior surface of the crystalline lens to the ATA line (the white line) is the crystalline lens rise (CLR). The anterior chamber width (ACW) from the scleral spur to the scleral spur (SS-SS) is also marked

recorded for both horizontal and vertical meridians. During measurement, the ciliary sulci must be fully exposed, and measurements should be taken at the attachment point of the root on the iris posterior surface when the ciliary sulcus morphology is normal; if the ciliary sulcus morphology is broad, measure the distance between both sides of bottom ends of the ciliary sulcus.

A single operator performed and reviewed all measurements to ensure consistency, with re-measurement and calibration for significant deviations. ICL size and diopters were determined using the manufacturer's Online Calculation and Ordering System (OCOS, http://www.ocos.staar.com/). Patients were grouped based on preoperative spherical equivalent (SE) into moderate myopia (-3.25 to -6.00 D), high myopia (-6.25 to -10.00 D), and super-high myopia (> -10.00 D).

ICLs surgery

An experienced surgeon (RBY) performed all surgeries. An EVO ICL (ICL-V4c, STAAR Surgical Co., Nidau, Switzerland) was inserted into the anterior chamber through a 3.0 mm corneal incision using an injector cartridge with 2% methylcellulose as a viscoelastic agent. The ICL haptics were positioned into the ciliary sulcus using a lens hook. After pressing the posterior edge of the corneal incision to expel the viscoelastic agent, residual viscoelastic was aspirated, and the corneal incision was sealed with a balanced salt solution. Gatifloxacin, bromfenac sodium and loteprednol were administered postoperatively to control inflammation and prevent infection.

Postoperative vault and ICL size evaluation

Postoperative vault evaluation was conducted one month after surgery. The central vault (distance between the posterior surface of the ICL and the anterior surface of the crystalline lens) was measured using AS-OCT. Eyes with vault within the ideal range (200–800 μm) were assessed to determine the proportion of ideal ICL size selection in each group (Fig. 2).

Statistical methods

The Kolmogorov–Smirnov test was used to determine the normality of the data distribution. Intergroup comparisons were made using one-way ANOVA for normally distributed data and non-parametric tests for non-normally distributed data. Pairwise comparisons were conducted using the Bonferroni correction. Chi-square tests were employed to study differences in composition ratios between groups, with α segmentation for pairwise comparisons. The ideal vault range was defined as 200–800 μm. A P-value < 0.05 was considered statistically significant. Statistical analysis was performed using SPSS (IBM®, SPSS® Statistics, v.26). A minimum sample size of 49 eyes for each group was needed to have a confidence level of 95% that the real value is within ± 5% of the measured value (PASS program 2021, v21.3.0).

Results

Basic characteristics

We ultimately analyzed 131 patients, totaling 246 eyes. The age range of the patients was 18 to 42 years, with 50 males and 81 females. The moderate myopia group (SE:

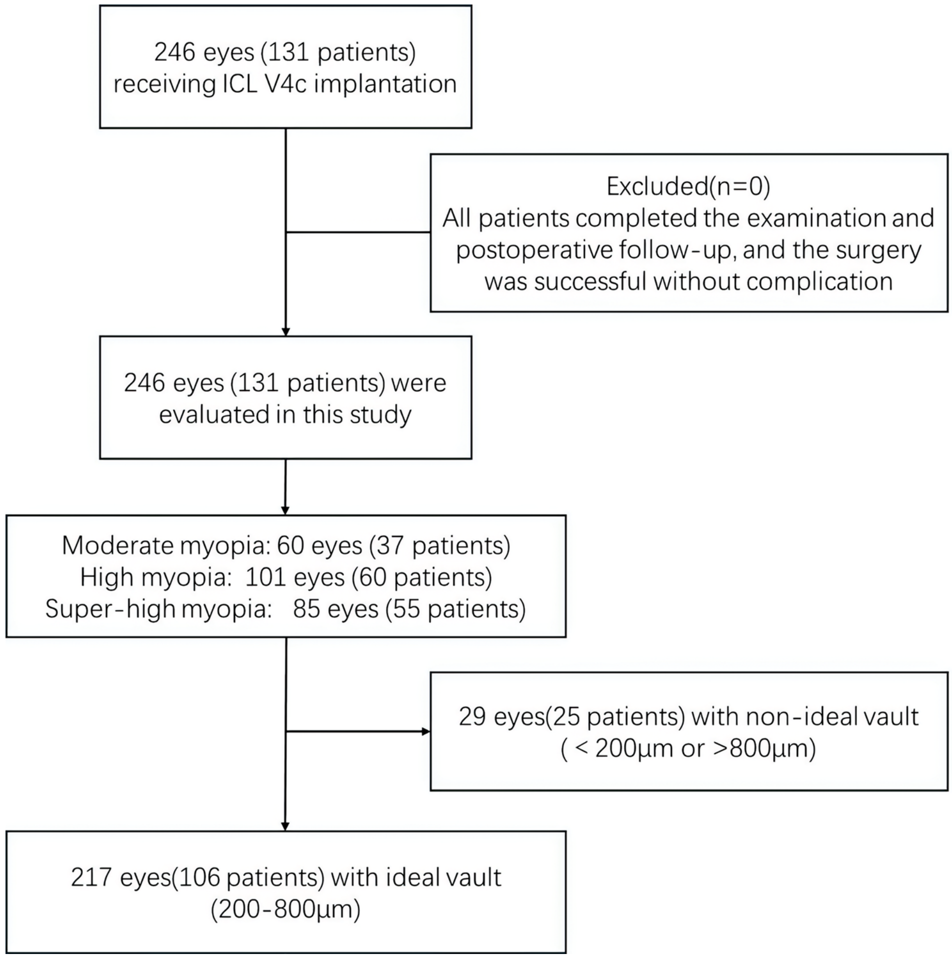

Fig. 2 Study profile

-3.25 to -6.00D) included 60 eyes, the high myopia group (SE: -6.125 to -10.00D) included 101 eyes, and the super-high myopia group (SE: -10.125 to -19.00D) included 85 eyes. The mean SE for each group was −4.94 ± 0.78D for moderate myopia, -8.01 ± 0.97D for high myopia, and -12.14 ± 3.40D for super-high myopia (Table 1).

Comparison of preoperative parameters

Table 1 shows the statistical differences in certain anterior segment parameters among the three different refractive groups. Significant differences were observed in AL, IOP, CCT, ACD, and TIA among the groups. The AL values for each group were: moderate myopia: 25.49 ± 0.98 mm, high myopia: 26.64 ± 0.99 mm, super-high myopia: 28.38 ± 1.30 mm ($P < 0.01$), indicating that AL became longer with the increase of myopic diopters. IOP was lowest in the moderate myopia (14.52 ± 2.48 mmHg) and highest in the super-high myopia group (15.65 ± 3.24mmHg), showing a significant difference between the moderate and super-high myopia ($P = 0.046$). Because of the thin cornea thickness in the moderate myopia group, the IOPs were corrected using Pentacam. The results showed no statistical difference in the three myopia groups ($P = 0.590$).

For ACD, the moderate myopia (3.17 ± 0.22 mm) had shallower ACD compared to the high myopia (3.26 ± 0.20 mm) and super-high myopia (3.25 ± 0.25 mm) ($P = 0.012$). No significant difference in ACD was observed between the high and super-high myopia groups ($P = 0.998$). TIA were smallest in the moderate myopia (48.24 ± 8.62°) and largest in the super-high myopia (54.43 ± 8.36°) ($P<0.001$). For CCT, There was a significant difference between the three groups ($P<0.001$). Moderate myopia, high myopia, and super-high myopia were 506 ± 30 µm, 517 ± 28 µm, and 529 ± 36 µm, respectively. This difference might be due to a bias from including patients with thin corneas in the moderate myopia group who were not suitable for corneal refractive surgery.

No significant differences were found in CLR among the different myopia groups. The range of CLR was larger in patients with high myopia (-386 to + 395) and super-high myopia (-450 to + 405) than in patients with moderate myopia (-340 to + 367). The proportion of CLR

Table 1 Baseline characteristics of patients and descriptive statistics for the three groups

	Moderate myopia	High myopia	Super-high myopia	P value	P value[a]	P value[b]	P value[c]
Eyes(n)	60	101	85				
Gender(M/F)	21/39	35/66	32/53	0.854	0.964	0.678	0.598
Age(years)	27.98 ± 5.26	27.21 ± 6.22	28.99 ± 7.90	0.371	0.666	0.423	0.163
SE Range (DS)	[-3.25~-6.00]	[-6.125~-10.00]	[-10.125~-19.00]				
SE(DS)	-4.94 ± 0.78	-8.01 ± 0.97	-12.14 ± 3.40	< 0.001*	< 0.001*	< 0.001*	< 0.001*
Kc(D)	43.57 ± 1.73	43.86 ± 1.47	43.75 ± 1.32	0.514	0.763	0.994	0.998
AL (mm)	25.49 ± 0.98	26.64 ± 0.99	28.38 ± 1.30	< 0.001*	< 0.001*	< 0.001*	< 0.001*
IOP (mmHg)	14.52 ± 2.48	14.84 ± 2.77	15.65 ± 3.24	0.037*	0.772	0.046*	0.137
Corrected IOP (mmHg)	17.02 ± 2.97	16.53 ± 2.96	16.63 ± 3.03	0.590	0.314	0.816	0.441
CCT (um)	506 ± 30	517 ± 28	529 ± 36	< 0.001*	0.105	< 0.001*	0.028*
ACD (mm)	3.17 ± 0.22	3.26 ± 0.20	3.25 ± 0.25	0.012*	0.014*	0.038*	0.998
WTW (mm)	11.57 ± 0.48	11.57 ± 0.37	11.55 ± 0.43	0.863	0.872	0.990	0.915
TIA (°)	48.24 ± 8.62	53.86 ± 9.93	54.43 ± 8.36	< 0.001*	0.001*	< 0.001*	0.881
LT (mm)	3.71 ± 0.32	3.65 ± 0.21	3.83 ± 0.37	0.062	0.864	0.495	0.058
CLR Range (um)	[-340~+367]	[-386~+395]	[-450~+405]				
CLR (um)	45(-53.5,114.7)	6(-113.5,108.5)	-6(-138,157)	0.176	0.127	0.211	0.763
CLR - (number of eyes)	21(35%)	51(50.5%)	47(55.3%)	0.047*	0.056	0.016*	0.514
CLR + (number of eyes)	39(65%)	50(49.5%)	38(44.7%)				

*$P < 0.05$; SE: spherical equivalent; Kc: central keratometry; DS: diopter sphere; AL: axis length; IOP: intraocular pressure; CCT: central corneal thickness; ACD: anterior chamber depth; WTW: white-to-white; ACA: anterior chamber angle; TIA: trabecular iris angle; LT: lens thickness, CLR: crystalline lens rise. P value comparing moderate myopia, high myopia, and super-high myopia; P value[a] comparing moderate myopia vs. high myopia; P value[b] comparing moderate myopia vs. super-high myopia; P value[c] comparing high myopia vs. super-high myopia

rise (+) was highest in the moderate myopia (65%) compared to the high myopia (49.5%) and super-high myopia (44.7%). The super-high myopia had the highest proportion of CLR fall (-) at 55.3%, compared to the moderate myopia (35%) and the high myopia (55.3%). The three groups showed significant differences ($P = 0.047$), with a notable difference between the moderate and super-high myopia ($P = 0.016$), indicating that the moderate myopia had more forward-placed lenses. In contrast, the super-high myopia had more backward-placed lenses. There were no significant differences between the moderate and high myopia or between the high and super-high myopia ($P = 0.056$, $P = 0.514$).

Other parameters, including Kc, WTW, and LT, showed no significant differences among the three groups ($P > 0.05$) (Fig. 3).

There were no significant differences in horizontal ATA (H-ATA), vertical ATA (V-ATA), horizontal ACW (H-ACW), vertical ACW (V-ACW), horizontal STS (H-STS), or vertical STS (V-STS) among the different myopia groups. H-STS was smaller than H-ATA and H-ACW. There were statistical differences in H-STS and H-ATA ($P < 0.001$), H-STS and H-ACW ($P < 0.001$). There were no significant differences in V-ATA, V-ACW, and V-STS (Table 2).

The vertical meridian measurements (V-ATA, V-ACW, and V-STS) were larger than the horizontal measurements (H-ATA, H-ACW, and H-STS), indicating vertical elliptical morphology in the anterior and posterior chambers. The difference in ΔSTS (V-STS - H-STS) (0.65 ± 0.38) was greater than the differences in ΔATA (V-ATA - H-ATA) (0.41 ± 0.38) and ΔACW (0.42 ± 0.37) (V-ACW - H-ACW) ($P < 0.001$), suggesting a more pronounced vertical elliptical shape in the posterior chamber compared to the anterior chamber (Fig. 4). There were no significant differences in ΔATA, ΔACW, or ΔSTS among the different myopia groups (Table 2).

Compared to the correlation in WTW, H-ACW, H-ATA, and H-STS among different myopia groups. The correlation in all refractive myopia was as follows: WTW and H-STS($r = 0.591$, $P < 0.001$), H-ACW and H-STS($r = 0.660$, $P < 0.001$), H-ATA and H-STS($r = 0.655$, $P < 0.001$). The correlation in moderate myopia was as follows: WTW and H-STS($r = 0.745$, $P < 0.001$), H-ACW and H-STS($r = 0.770$, $P < 0.001$), H-ATA and H-STS($r = 0.770$, $P < 0.001$). The correlation in high myopia was as follows: WTW and H-STS($r = 0.432$, $P < 0.001$), H-ACW and H-STS($r = 0.563$, $P < 0.001$), H-ATA and H-STS($r = 0.565$, $P < 0.001$). The correlation in super-high myopia was as follows: WTW and H-STS($r = 0.631$, $P < 0.001$), H-ACW and H-STS($r = 0.643$, $P < 0.001$), H-ATA and H-STS($r = 0.625$, $P < 0.001$) (Fig. 5). The results showed that the correlation in H-ACW and STS, H-ATA and STS were higher than that between WTW and STS, and the same correlation results were observed in moderate myopia and high myopia groups. In the super-high myopia group, the correlation between H-ACW and STS, WTW, and STS was slightly higher than that between ATA and STS.

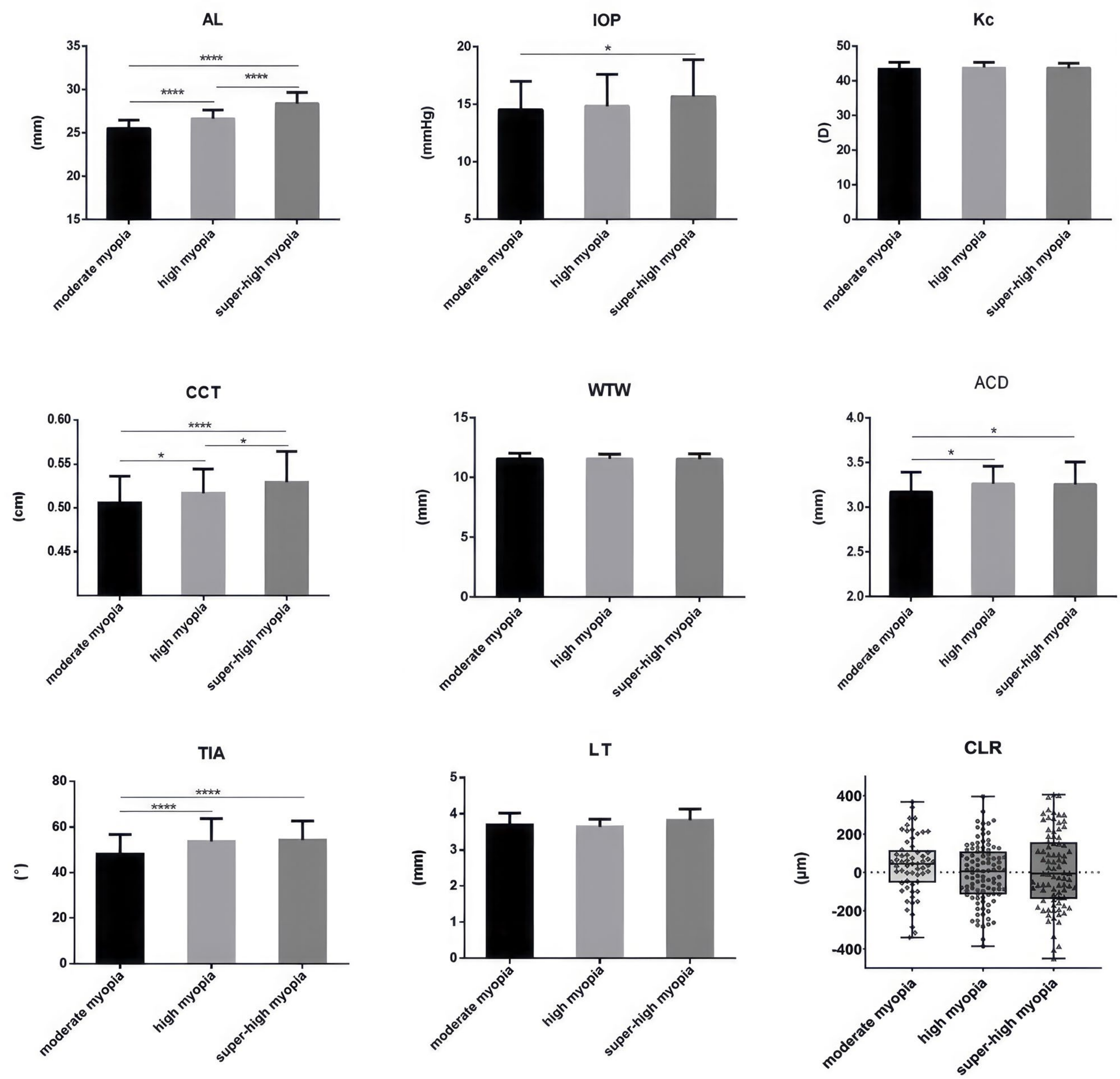

Fig. 3 Comparison of preoperative parameters in the three myopia groups: axial length (AL) in millimeters; (IOP) in mmHg; central keratometry (Kc) in diopters; central corneal thickness (CCT) in micrometers; white-to-white (WTW) in millimeters; Internal anterior chamber depth (ACD) in millimeters; trabecular iris angle (TIA)in; lens thickness (LT)in millimeters; crystalline lens rise (CLR) in micrometers

ICL size selection

The ICL size was determined using the manufacturer's OCOS calculation formula. The 12.6 mm size had the highest selection proportion in each group: 40.0% in moderate myopia, 63.4% in high myopia, and 44.7% in super-high myopia. The ICL size and proportions in moderate myopia were: 12.1 mm (19 eyes, 31.7%), 12.6 mm (24 eyes, 40.0%), and 13.2 mm (17 eyes, 28.3%). In the high myopia, the ICL size and proportions were: 12.1 mm (14 eyes, 13.9%), 12.6 mm (64 eyes, 63.4%), and 13.2 mm (23 eyes, 22.8%). In the super-high myopia, the ICL size and proportions were: 12.1 mm (20 eyes, 23.5%), 12.6 mm (38 eyes, 44.7%), and 13.2 mm (27 eyes, 31.8%) (Fig. 6).

One month postoperatively, vault measurements showed no significant differences among the three groups ($P = 0.763$). The vaults in the ideal range (200–800 μm) were 88.3%, 87.1%, and 89.4% for moderate, high, and super-high myopia, respectively, with no significant differences ($P = 0.891$). Only 2 eyes (2%) in the high myopia had a vault < 200 μm. The proportions of vaults > 800 μm were 11.7%, 10.9%, and 10.6% for moderate, high, and

Table 2 Horizontal and vertical ACW, ATA, and STS in different groups

Parameter	All	Moderate myopia	High myopia	Super-high myopia	*P* value
ATA					
Horizontal ATA	11.71 ± 0.41	11.68 ± 0.50	11.67 ± 0.36	11.76 ± 0.40	0.28
Vertical ATA	12.13 ± 0.41	12.11 ± 0.53	12.09 ± 0.37	12.18 ± 0.37	0.337
P value[a]	< 0.001*	< 0.001*	< 0.001*	< 0.001*	
ACW					
Horizontal ACW	11.66 ± 0.42	11.63 ± 0.51	11.63 ± 0.36	11.70 ± 0.41	0.433
Vertical ACW	12.07 ± 0.42	12.03 ± 0.54	12.05 ± 0.37	12.12 ± 0.38	0.436
P value[b]	< 0.001*	< 0.001*	< 0.001*	< 0.001*	
STS					
Horizontal STS	11.48 ± 0.53	11.48 ± 0.59	11.40 ± 0.49	11.56 ± 0.53	0.171
Vertical STS	12.12 ± 0.56	12.15 ± 0.65	12.06 ± 0.52	12.18 ± 0.53	0.304
P value[c]	< 0.001*	< 0.001*	< 0.001*	< 0.001*	
P value[d]	< 0.001*	0.099	< 0.001*	0.019*	
P value[e]	0.230	0.511	0.701	0.491	
ΔATA	0.42 ± 0.24	0.43 ± 0.26	0.42 ± 0.23	0.42 ± 0.25	0.941
ΔACW	0.41 ± 0.24	0.39 ± 0.26	0.42 ± 0.22	0.42 ± 0.26	0.739
ΔSTS	0.65 ± 0.38	0.67 ± 0.35	0.66 ± 0.43	0.62 ± 0.34	0.735
P value[f]	< 0.001*	< 0.001*	< 0.001*	< 0.001*	
P value[g]	0.982	0.999	0.999	0.999	
P value[h]	< 0.001*	< 0.001*	< 0.001*	< 0.001*	
P value[i]	< 0.001*	< 0.001*	< 0.001*	< 0.001*	

*$P < 0.05$; ACW: anterior chamber width; ATA angle-to-angle distance; STS Sulcus-to-Sulcus; P value comparing moderate myopia, high myopia, and super-high myopia; ΔACW: vertical ACW- horizontal ACW; ΔATA: vertical ATA-horizontal ATA; ΔSTS: vertical STS- horizontal STS

P value[a] comparing horizontal ATA vs. vertical ATA

P value[b] comparing horizontal ACW vs. vertical ACW

P value[c] comparing horizontal STS vs. vertical STS

P value[d] comparing horizontal ATA, horizontal ACW, and horizontal STS

P value[e] comparing vertical ATA, vertical ACW and vertical STS

P value[f] comparing ΔATA, ΔACW and ΔSTS

P value[g] comparing ΔATA vs. ΔACW

P value[h] comparing ΔATA vs. ΔSTS

P value[i] comparing ΔACW vs. ΔSTS

super-high myopia, respectively, with no significant differences ($P = 0.979$).

Excluding data with non-ideal vaults (< 200 μm and > 800 μm), the proportions of suitable ICL size within the ideal vault range (200–800 μm) were re-evaluated. The proportions of ICL size in the moderate myopia group were: 12.1 mm (19 eyes, 35.8%), 12.6 mm (22 eyes, 41.5%), and 13.2 mm (12 eyes, 22.6%). In the high myopia group, the proportions were: 12.1 mm (13 eyes, 14.6%), 12.6 mm (62 eyes, 69.7%), and 13.2 mm (14 eyes, 15.7%). In the super-high myopia group, the proportions were: 12.1 mm (20 eyes, 26.3%), 12.6 mm (35 eyes, 46.1%), and 13.2 mm (21 eyes, 27.6%) (Fig. 6). The 12.6 mm size remained the most commonly selected across all groups. The proportion of 12.1 mm in the moderate myopia group was the highest ($P = 0.013$), and there was a statistical difference compared with the high myopia group($P = 0.003$). The proportion of 12.6 mm was the highest in the high myopia group ($P = 0.001$), and there were statistical differences between the high myopia group and the moderate myopia group ($P = 0.001$) and the high myopia group and the super-high myopia group ($P = 0.002$). The high myopia group had the highest proportion of 13.2 mm, but there was no statistical difference between the three groups ($P > 0.05$).

Discussion

In this study, we primarily evaluated the anterior segment parameters and ICL size selection in patients with varying degrees of myopia. The indication for ICL implantation recommends an ACD > 2.8 mm, as a shallow ACD suggests a small anterior chamber space, which may lead to low vault and increase the risk of lens opacity. Research indicates that vault is related to preoperative ACD [18, 19], and findings suggest that preoperative ACD influences the individual's range for vault [20]. Therefore, a deeper anterior chamber can accommodate a larger range of vault, while a shallower chamber would have a smaller ideal vault range. Our study found that the ACD in the moderate myopia group was smaller than in the high and super-high myopia groups. Meanwhile, moderate myopia has the smallest TIA. The higher myopic diopters, the larger TIA. Hence, the moderate myopia group has less anterior chamber space than the high and super-high myopia groups, suggesting that the tolerance range for an ideal vault postoperatively in moderate myopia patients is smaller, particularly in those with higher vaults; therefore, vigilance is needed for these patients regarding their vault, anterior chamber angle, and IOP. Besides, ACD measurement error can contribute to inaccuracy of intraocular lens power, which request the more accuracy of preoperative ocular biometry [21, 22]. The use of optical biometers for the best precision of measurement is recommended. AS-OCT is faster and provides more in-depth assessment of the anterior chamber and is repeatable and reproducible [23]. In our research, AS-OCT was used to measure the anterior chamber parameters.

Studies have shown that CLR significantly impacts ACD and postoperative ICL vault [24, 25], with CLR negatively correlated with ACD and vault. Therefore, CLR is considered an essential parameter for predicting vault [16, 26]. This study showed the proportion of CLR + was higher in the moderate myopia group. With the increase of myopic degrees, the proportion of CLR + decreased,

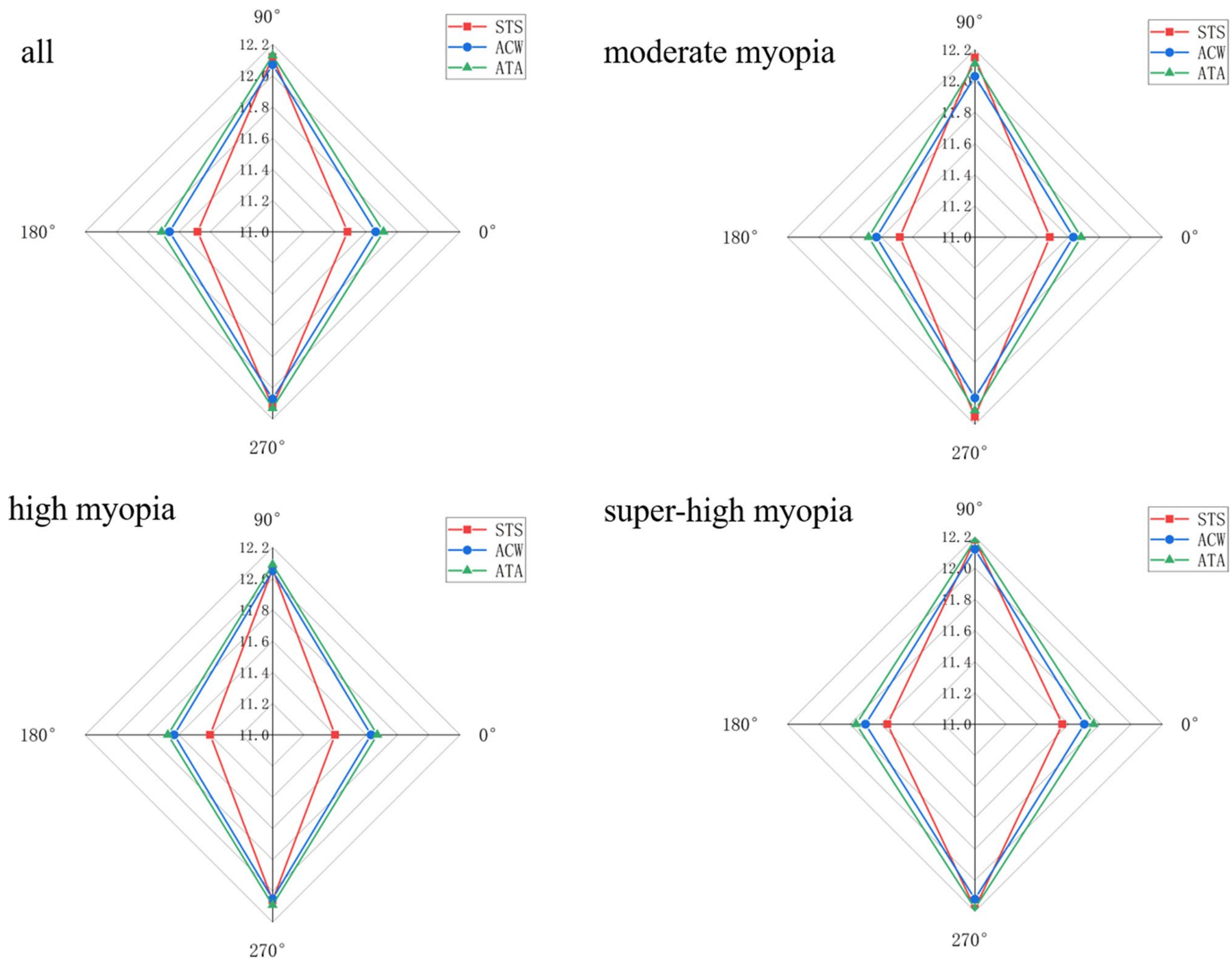

Fig. 4 The general outline of STS, ACW, and ATA for the whole eye in different degrees of myopia groups. The STS (red line)、ACW (blue line) and ATA(green line) contour followed a vertical ellipse shape. Note that the radial axis begins at a 11 mm diameter

and the proportion of CLR- increased. This trend may be related to the negative correlation with ACD, as the moderate myopia group has a smaller ACD, placing the lens in a more anterior position. The study also shows that the range of CLR is greater in the high and super-high myopia groups than in the moderate myopia. Given that LT shows no difference among different myopia groups, we speculate that the greater CLR range in high and super-high myopia patients may be related to zonular function. This suggests that preoperative attention should be given to zonular function in high and super-high myopia patients. Additionally, age could be a factor influencing CLR, with CLR values increasing with age, possibly due to continued lens growth with aging [27].

ATA and ACW represent the horizontal diameters of the anterior chamber. STS is the distance between the ciliary sulci, representing the posterior chamber diameter where the ICL is placed. Our results showed no significant differences in horizontal and vertical ATA, ACW, and STS among different myopia groups, indicating no significant differences in the average anterior and posterior chamber diameters across patients with varying levels of myopia. Thus, combined with the ACD results, we can infer that ACD influences anterior segment space in myopia patients of different degrees. When selecting ICL size, the moderate myopia group with shallower ACD and smaller TIA is more likely to require smaller ICL sizes.

Recently, formulas based on ATA, ACW, and STS parameters for predicting ICL size and vault have been developed [28–30]. Our study showed that STS has better correlations with ATA and ACW than WTW. Across different refractive groups, the correlation between ACW and STS was better than between WTW and STS, and ATA correlated with STS better than WTW in the moderate and high myopia groups. Considering the high reproducibility of ATA and ACW parameters provided by anterior segment OCT and minimizing manual measurement errors, ATA and ACW are likely replace WTW for ICL sizing calculations in the future.

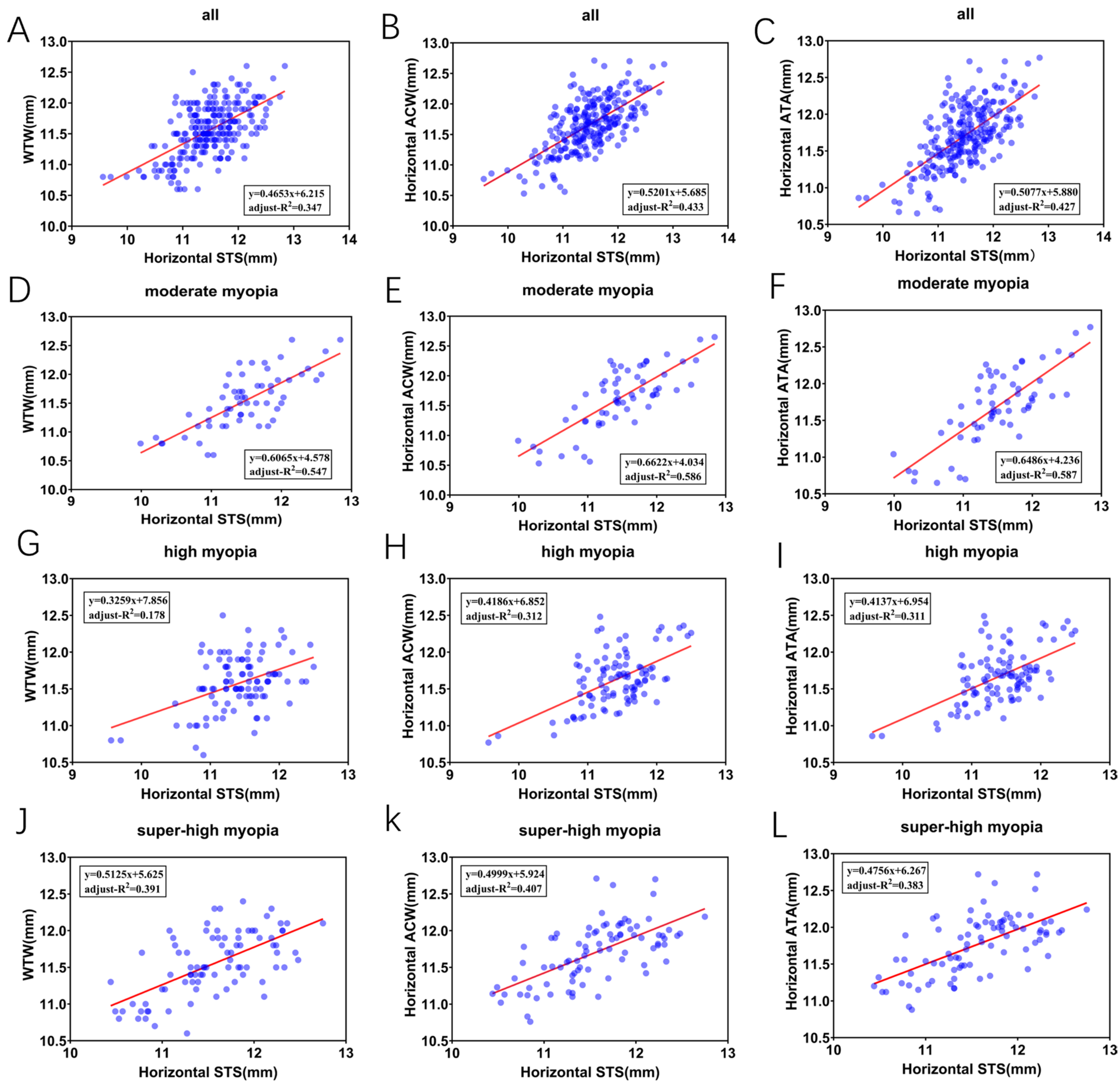

Fig. 5 The correlation of H-STS, WTW, H-ACW, and H-ATA in different degrees of myopia. **A**, **B**, **C**: all myopia patients; **D**, **E**, **F**: moderate myopia group; **F**, **H**, **I**: high myopia group; **J**, **K**, **L**: super-high myopia group

Additionally, this study measured the vertical meridian ATA, ACW, and STS using CASIA2. The results were consistent with previous studies [31], confirming that the anterior and posterior chambers are vertically elliptical, with the posterior chamber being more vertically elliptical than the anterior chamber. This provided a theoretical basis for ICL position adjustment (from horizontal to vertical axis) to reduce vertically elliptical the undesirable high vault. Because it did not differ in three myopia groups, non-Toric ICL position adjustment is effective across different refractive groups.

Postoperative vault is influenced by ocular anatomy and ICL size [32, 33]. Su3boptimal ICL size and insufficient vault are the primary reasons for ICL replacement. Thompson et al. reviewed alternative ICL planning and sizing approaches to guide surgeons in implanting ICLs [34]. Our study showed that the proportion of eyes with a postoperative vault in the range of 200–800 μm were 88.3%, 87.1%, and 89.4% in different myopia groups, respectively. Excluding these eyes with non-ideal vaults, the analysis of ICL size distribution within the ideal vault range revealed that the 12.6 mm ICL was the most frequently selected across all groups, especially with 69.7%

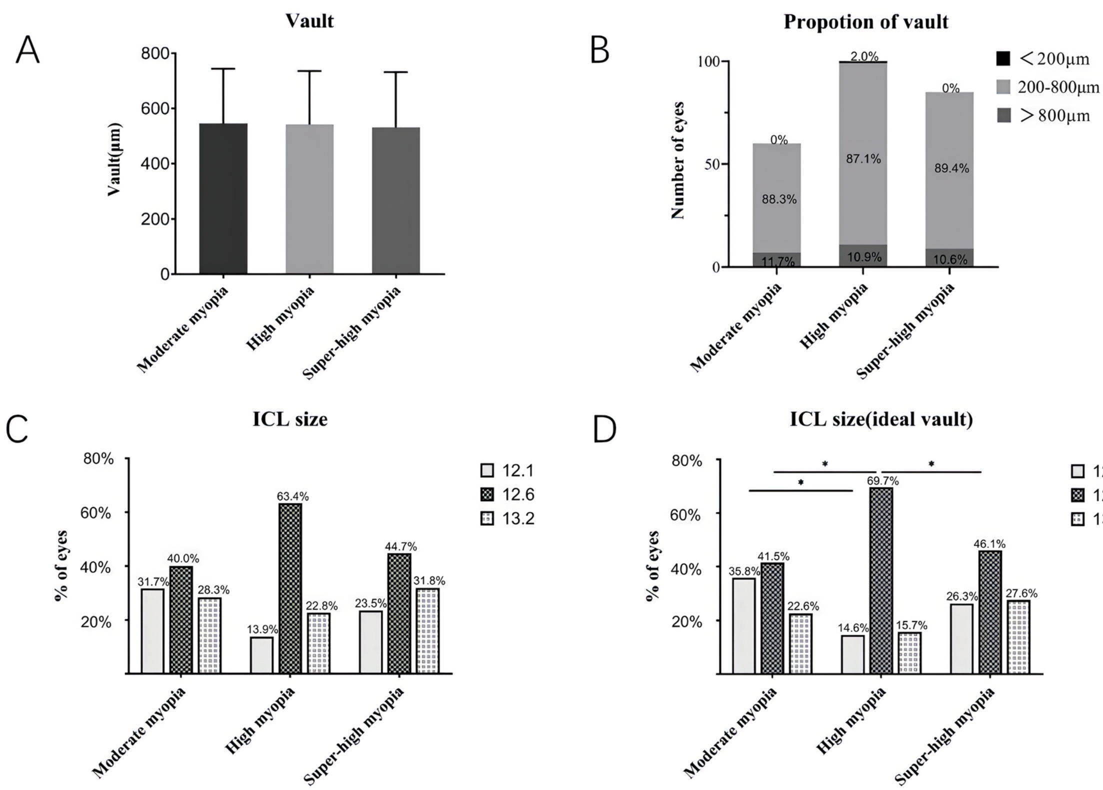

Fig. 6 Comparison of postoperative vault and ICL size in the three myopia groups: **A.** Comparison of the vault in the three myopia groups; **B**. Number of eyes and proportion with different ranges of vault (< 200 μm,200–800 μm,800 μm) in the three myopia groups; **C**. Proportion of ICL size (12.1 mm,12.6 mm,13.2 mm) with actual implantation in each myopia group; **D.** Proportion of ICL size (12.1 mm,12.6 mm,13.2 mm) with ideal vault in each myopia group

in the high myopia group. In the moderate myopia group, eyes with a small ACD and a narrow TIA tended to select smaller ICLs (12.1 mm, 35.8%).

In this study, the CCT showed statistical differences among different degrees of myopia, with moderate myopia having thinner CCT compared to high and super-high myopia. The reason is that in the moderate myopia group, most of the patients with thin cornea were unsuitable for corneal refractive surgery, which may have introduced bias.

The limitations of this study include a small sample size, single-center research, and data that may only represent part of the Asian population. Contrary to Hoffer's protocol, both eyes of 106 patients were included [35]. Future research with larger sample sizes is needed to validate these findings and further explore changes in anterior segment parameters after ICL implantation in different degrees of myopia.

In conclusion, this study confirmed that the anterior segment parameters, ACD and TIA, were smaller in moderate myopia than the high and super-high myopia while similar WTW, ATA, ACW and STS, with the lens position being more anterior. Therefore, for different degrees of myopia, the differences in ICL size were more influenced by sagittal axis parameters. The range of CLR was greater in high and super-high myopia patients, which suggested that we should pay more attention to the zonule function before ICL implantation. The vertical elliptical shape was more evident in the posterior chamber than in the anterior chamber, which confirmed that non-Toric ICL repositioning (from horizontal to vertical axis) was effective across different refractive groups. Furthermore, STS showed a higher correlation with ATA and ACW that are likely replace WTW for ICL sizing calculations in the future.

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Author contributions
FL and YM wrote the main manuscript text. FL prepared Table 1 and 2; Figs. 1, 2 and 3. YM prepared Figs. 4, 5 and 6. RY, SZ and EP reviewed the manuscript. RY provided the main idea. WQ collected patients' clinical data.

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Data availability
In addition to the data provided in the manuscript, the other datasets used and/or analyzed in the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
The study protocol was approved and the requirement to obtain informed written consent was waived by the Ethics Committee of Tianjin Medical University Eye Hospital (No.2021KY(L)-18). This study was performed in accordance with the tenets of the Declaration of Helsinki.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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