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Lens height paraments comparison according to ciliary sulcus width (CSW): a pilot study of the predictive role of CLR and STSL for vault after ICL implantation

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Abstract

Background To assess the relationship between postoperative implantable collamer lens (ICL) vault and lens height obtained from two different measurements.

Methods A retrospective case series study enrolled eyes with horizontally implanted ICL. Crystal lens rise (CLR) and the distance between STS plane and anterior crystalline lens surface (STSL) were measured in the horizontal and vertical directions using ultrasound biomicroscopy (UBM). We compared the differences in the parameters measured in both horizontal and vertical directions. The participants were categorized into three groups according to ciliary sulcus width (CSW) which is defined as the distance between the posterior angle of the iris and the anterior angle of the ciliary process: narrow CSW group (NSG); medium CSW group (MSG); and wide CSW group (WSG). The correlations between CLR/STSL and vault were examined in each of the three groups. Biased correlation analysis was used further to contrast the correlation between CLR/STSL and vault.

Results This retrospective study included 223 myopic eyes. Vertical STSL (VSTSL) and vertical CLR (VCLR) exhibited significantly greater values compared to their horizontal counterparts (both $P < 0.05$). None of the indicators were statistically different between the three groups. In both NSG and MSG, STSL/CLR correlated with vault, while in WSG, only STSL correlated with vault (r=-0.316, $P = 0.013$). In contrast to HCLR, the correlation between HSTSL and vault remained after controlling for HCLR (r=-0.162, $P = 0.015$).

Conclusions STSL should deserve more attention in the preoperative evaluation of ICL compared to CLR especially when CSW is large.

Keywords Implantable collamer lens, Lens height, Orientation, Ciliary sulcus width, Vault

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Background

Vault is a crucial indicator for assessing safety following implantable collamer lens (ICL) implantation. In general, an excessively low vault is associated with an increased incidence of anterior subcapsular cataracts [1], whereas an excessive vault is linked to an elevated risk of pigment dispersion and angle closure [2, 3], and the size of the ICL crystals chosen by the surgeon directly impacts vault. A study has shown that a thicker or more anteriorly positioned lens reduces vault [4]. For this reason, the researchers have used lens height which is defined as the relative height of the apex of the anterior surface of the lens from a given baseline to represent the effect of the lens on vault. However, there is no universally accepted definition of lens height. Two primary classifications: one is crystal lens rise (CLR) introduced by Baïkoff et al. [5] in 2006, and the other is the distance between STS plane and the anterior crystalline lens surface (STSL) proposed by Kojima et al. [6] in 2012. The two parameters show a negative correlation with vault [7, 8] and both are considered to be identified as significant independent variables in the ICL crystal size selection formula [9, 10]. Recently, Fan et al. [11] found that CLR differed horizontally and vertically (vertically greater than horizontally). To the best of our knowledge, no study has analyzed these two lens heights in detail to clarify whether this difference also exists in STSL and, more crucially, to clarify which parameter is of greater concern to the clinician in predicting postoperative vault.

This study utilized ultrasound biomicroscopy (UBM) to measure and analyze the distribution of two lens heights in both horizontal and vertical directions, investigating their relationships with other ocular parameters. Discussion of subgroups according to ciliary sulcus width (CSW) and biased correlation analysis were used further to contrast the correlation between CLR/STSL and vault.

Methods

Patients

This retrospective study included 223 eyes of 117 patients who underwent ICL implantation for myopic and astigmatism correction in the Eye Center of the Second Affiliated Hospital of Zhejiang University School of Medicine from September 2022 to February 2024. Inclusion criteria: age between 18 and 40 years, myopia stabilized for more than 2 years, anterior chamber depth (ACD) ≥ 2.8 mm, and implanted ICL lenses were required to be placed horizontally (rotated no more than 22.5° around the horizontal line [8]); exclusion criteria: patients with any eye disease. The study protocol was approved and the requirement to obtain informed written consent was waived by the Ethics Committee of the Second Affiliated Hospital of Zhejiang University School of Medicine. (NO: IR2023454). This study was performed in accordance with the tenets of the Declaration of Helsinki.

Examinations

All patients are required to undergo a comprehensive eye examination, including uncorrected distance visual acuity (UDVA) and corrected distance visual acuity (CDVA), manifest and cycloplegic refraction, intraocular pressure (IOP) (non-contact tonometry, Canon, Japan), corneal endothelial cell density (ECD) (noncontact specular microscopy, SP-3000P, Topcon Corporation, Japan), scheimpflug tomography with Pentacam (Pentacam HR Oculus, Wetzlar, Germany) for ACD, horizontal white to white (HWTW), anterior chamber volume (ACV) and anterior chamber angle (ACA) measurement, IOL-Master 700 (Carl Zeiss Meditec, Jena, Germany) for lens thickness (LT) and axial length (AL), dilated fundus examination using a 90 D, anterior segment parameter measurements with UBM (Model SW-3200 L, Tianjin Suowei Electronic Technology Co, Ltd, Tianjin, China). The same examination and measurements are done by the same experienced physician.

Definition of UBM variables

UBM measurements were performed in a controlled lighting room (approximately 120 lx). The patient was asked to lie in the supine position, and an appropriately sized plastic eye cup filled with normal saline was placed in the conjunctival sac after topical anesthesia. To reduce the influence of accommodation, participants were then asked to keep their eyes fixed on the ceiling. The operator turned on the image acquisition mode and adjusted the ultrasound probe so that it was perpendicular to the center of the cornea. Cross-sectional scans were performed on the horizontal and vertical (90° and 180°) meridians in the state of non-ciliary muscle paralysis. Pictures showing the strongest reflections from the cornea, anterior lens capsule, and posterior lens capsule are considered eligible. The following indicators were repeated three times for each eye to ensure the accuracy of the results. (1) Distance of ciliary sulcus-to-sulcus (STS), the iris root attachment point distance. We refer to Chang et al. [12] for the measurement of STS. If the root of the iris is separated from the root of the anterior surface of the ciliary processes, STS is considered to be the distance between the basal ends of the ciliary sulcus on each side. (2) Distance of angle-to-angle (ATA), the distance between the two anterior chamber angle vertices in a line. (3) STSL, the distance between STS plane and the anterior crystalline lens surface; CLR, the distance between ATA plane and the anterior crystalline lens surface. The STSL/CLR value is defined as positive if the lens apex is located in front of the STS/ATA line. Conversely, the other one is negative. (4) CSW, the distance between the posterior

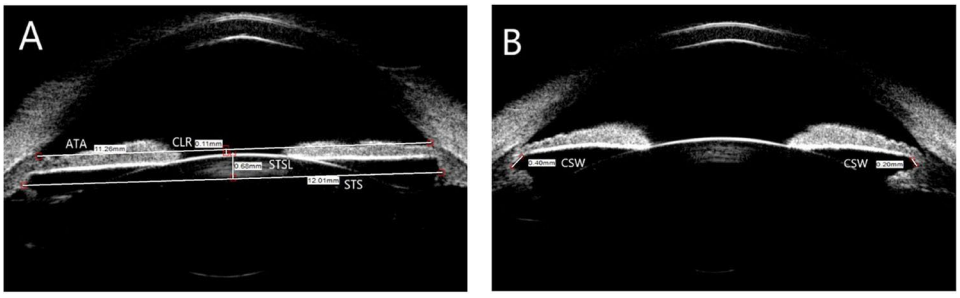

Fig. 1 Parameters were determined on UBM images scanned horizontally and vertically over the full field of view centered on the pupil. **A** STS, the distance of ciliary sulcus-to-sulcus; ATA, the distance of angle-to-angle; STSL, the distance between STS plane and anterior crystalline lens surface; CLR, crystal lens rise. **B** CSW, ciliary sulcus width, calculate the average of the values on both sides, CSW = 0.30 mm in **B**

angle of the iris and the anterior angle of the ciliary process [13, 14]. We used the magnification function provided by the UBM to observe the ciliary sulcus region of each image in detail. In our measurements, we found that CSW essentially reflects the positional relationship between the iris and the ciliary process, with two main scenarios: a relatively obvious space exists at the root of both; and only root contact or close contact between the two, in which case CSW is 0. If there is any doubt about CSW measurement of a particular image, we would choose another clear image to measure again or eliminate that eye. Finally, we calculate the average of CSW on both sides as CSW in that direction.

The above parameters are prefixed with "H" for horizontal direction and "V" for vertical direction. The same examination and measurements are done by the same experienced physician. All eyes were divided into three groups based on HCSW: narrow ciliary sulcus width group (NSG): HCSW ≤ 0.150 mm; medium ciliary sulcus width group (MSG): 0.150 mm < HCSW ≤ 0.250 mm; wide ciliary sulcus width group (WSG): HCSW > 0.250 mm. Parameters measured using UBM are shown in Fig. 1.

The appropriate ICL crystal size is selected based on STAAR online calculation and clinical experience, and all eye surgeries are performed by the same experienced surgeon. Recording of vault measured by a high-resolution anterior segment optical coherence tomography (AS-OCT, CASIA, Tomey Corporation, Aichi, Japan) at 1 month postoperatively.

Statistical analysis

All data were tested for normality using the Kolmogorov-Smirnov method. Where normal information was described as mean ± standard deviation, the differences between CSW subgroups were analyzed by one-way ANOVA, and each parameter's variability in vertical and horizontal directions was analyzed by paired t-test. The skewed data were described as M (Q1, Q3), the differences between CSW subgroups were analyzed using the Kruskal-Wallis test followed by the Bonferroni post hoc test, and the variability of each parameter in vertical and horizontal directions was analyzed by the Wilcoxon signed-rank test. The chi-square test was used to compare the proportion of sex, and the ratio of ICL size among the three groups. Pearson or Spearman correlation coefficients were used to test the correlation between the parameters. The association between HCLR/HSTSL and vault was further explored by partial correlation analysis. All statistical analyses were performed using the R software (version 4.1.1), and a two-sided test of $P < 0.050$ was considered statistically significant.

Table 1 Comparison of vertical and horizontal parameters using UBM

Parameter	Vertical	Horizontal	Difference	*P*
STS (mm)	12.11 ± 0.52	11.64 ± 0.50	0.47 ± 0.37	< 0.001
ATA (mm)	11.83 ± 0.51	11.56 ± 0.49	0.27 ± 0.30	< 0.001
STSL (mm)	0.52 ± 0.21	0.38 ± 0.20	0.14 ± 0.15	< 0.001
CLR (mm)	0.12 ± 0.19	0.02 ± 0.19	0.10 ± 0.14	< 0.001
CSW (mm)	0.23 (0.17, 0.30)	0.18 (0.13, 0.26)	0.04 (-0.04, 0.11)	< 0.001

STS: distance of ciliary sulcus-to-sulcus; ATA: distance of angle-to-angle; STSL: the distance between STS plane and anterior crystalline lens surface; CLR: crystal lens rise; CSW: ciliary sulcus width

Results

A total of 223 eyes of 117 patients aged 27.00 (23.00, 32.00) years were analyzed. For all eyes, the mean preoperative SE was −9.06 ± 2.55 D, the mean AL was 27.13 ± 1.37 mm, and the mean vault at 1 month postoperatively was 590.51 ± 218.24 μm.

Non-uniform distribution of lens height horizontally and vertically

Table 1 provides the parameters of the UBM measurements, and there are statistical differences between STS, ATA, STSL, CLR, and CSW in the vertical direction and the corresponding values in the horizontal direction, which are overall greater vertically than horizontally. Notably, VSTSL > HSTSL in 190 eyes (85.2%); and VCLR > HCLR in 176 eyes (79.0%). Furthermore, the mean value of the difference between VSTSL and HSTSL (VSTSL - HSTSL) is 0.14 ± 0.15 mm with a

maximum value of 0.60 mm; the mean value of the difference between VCLR and HCLR (VCLR - HCLR) is 0.10±0.14 mm with a maximum value of 0.45 mm. Interestingly, the two maxima appear in the same eye. In general, (VSTSL - HSTSL) was larger than (VCLR - HCLR), with a mean difference of 0.03±0.13 mm, which was statistically significant ($p<0.001$). In 137 eyes (61.43%) of the observed eyes, (VSTSL - HSTSL) exceeded (VCLR - HCLR). Still, 77 eyes (34.53%) had a larger (VCLR - HCLR). The correlations between CLR/STSL and other parameters are shown in Fig. 2. STSL/CLR in both horizontal and vertical directions were positively correlated with age and LT (both $P<0.05$), and negatively correlated with ACD, ACV, and ACA (all $P<0.05$). A negative correlation was found between HCLR and AL ($P=0.005$). While VCLR, HSTSL, and VSTSL were not significantly correlated with AL.

Compare the predictive ability of CLR/STSL for vault

To make our conclusions more plausible, ICL lenses were requested to be implanted horizontally in all eyes in this study to explore the effect of HCSW on horizontal implantation. Table 2 provides preoperative demographic characteristics of the patients undergoing ICL implantation in different CSW groups. According to the mean HCSW value, the subjects were divided into three groups: 89 eyes in NSG, 73 eyes in MSG, and 61 eyes in WSG, and all the indicators listed in Table 2 were not statistically different between the three groups except for HCSW. Table 3 shows the correlation between the two lens heights and vault after grouping according to HCSW. Both HCLR and HSTSL were correlated with vault in all cases except in WSG where HCLR was not significantly correlated with vault. In NSG, both HCLR and HSTSL were moderately correlated with vault (r=-0.451, $P<0.001$; r=-0.420, $P<0.001$). The results of the biased correlation are displayed in Fig. 3. In contrast to HCLR, the correlation between HSTSL and vault remained after controlling for HCLR (r=-0.162, $P=0.015$).

Discussion

The measurement of lens height in ICL is not standardized at now. To our knowledge, this is the first attempt to provide a detailed analysis of the disparities between CLR/STSL in horizontal and vertical orientations and evaluate the correlation between CLR/STSL and vault using two different methodologies. These will help clinicians increase their knowledge of CLR/STSL and guide ICL crystal size selection, thereby increasing the rate of ideal vault after surgery.

CLR can be measured directly by AS-OCT, while STSL is associated with the ciliary body, its measurement needs to be done with the help of a more penetrating UBM [15]. However, both CLR and STSL measurements in this study were performed in the UBM, and this choice was purposeful for several reasons: firstly CLR is more comparable to STSL when measured under the same conditions as it was found that light [7], and physiological conditioning [16, 17] affect the magnitude of CLR and STSL; secondly, the study by Bu et al. [18] clearly states that there is no significant difference between CLR measured by AS-OCT and UBM; and thirdly Ghoreishi et al. [19] also measured ATA and CLR using UBM.

The present study first observed that VCLR was greater than HCLR which is consistent with the findings of Fan et al. [11]. In addition, the same results, consistent with what we expected, were also seen in the STSL. Since the apex of the lens's anterior surface is considered to be the same point in both horizontal and vertical images, this means that the two STS lines must be located in different coronal planes, in agreement with the results of the ATA [11]. For easier understanding, we plotted Fig. 4 to illustrate that HSTS is not on the same coronal plane as VSTS, and VSTS is closer to the posterior

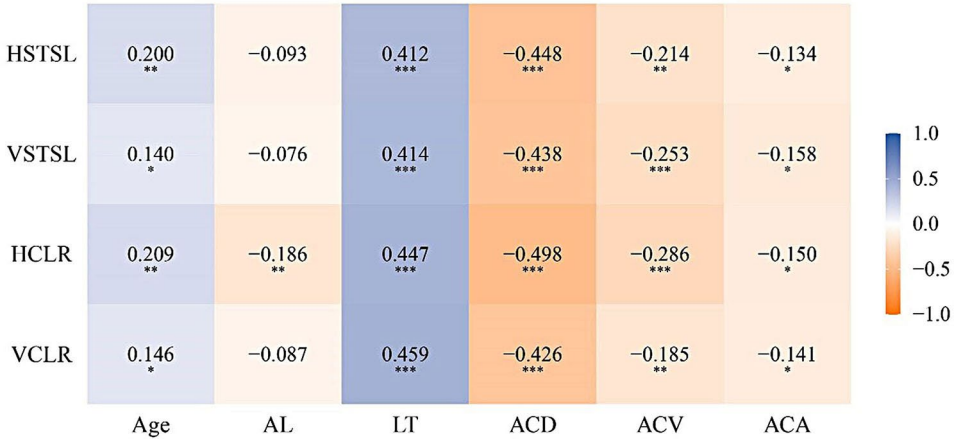

Fig. 2 Correlation between CLR/STSL and other parameters. AL, axial length; LT, lens thickness; ACD, anterior chamber depth; ACV, anterior chamber volume; ACA, anterior chamber angle; HSTSL, horizontal STSL; VSTSL, vertical STSL; HCLR, horizontal CLR; VCLR, vertical CLR. * $P<0.05$; ** $P<0.01$; *** $P<0.001$

Table 2 Preoperative demographic characteristics of the patients undergoing ICL implantation in different HCSW groups

Parameter	NSG (HCSW ≤ 0.150)	MSG (0.150 < HCSW ≤ 0.250)	WSG (HCSW > 0.250)	*P*
Eyes	89	73	61	
Gender, male/female	26/63	25/48	18/43	0.770
Age (yrs)	27.00 (22.50, 30.00)	28.00 (22.50, 32.00)	28.00 (23.00, 32.00)	0.162
SE (D)	-9.10 ± 2.49	-9.13 ± 2.51	-8.92 ± 2.73	0.882
ICL size, %				0.447
12.1	10 (11.24)	11 (15.07)	10 (16.39)	
12.6	41 (46.07)	25 (34.25)	28 (45.90)	
13.2	32 (35.96)	34 (46.58)	22 (36.07)	
13.7	6 (6.74)	3 (4.11)	1 (1.64)	
AL (mm)	27.21 ± 1.37	27.21 ± 1.34	26.93 ± 1.41	0.408
LT (mm)	3.63 ± 0.22	3.72 ± 0.28	3.64 ± 0.24	0.066
HWTW (mm)	11.68 ± 0.42	11.61 ± 0.44	11.55 ± 0.42	0.208
ACD (mm)	3.26 ± 0.23	3.26 ± 0.27	3.30 ± 0.26	0.651
ACA (°)	39.00 (35.35, 42.30)	37.70 (34.95, 42.25)	38.80 (36.30, 41.80)	0.611
ACV (mm^3)	212.49 ± 29.82	211.10 ± 33.00	209.69 ± 34.81	0.871
HATA (mm)	11.62 ± 0.47	11.54 ± 0.48	11.49 ± 0.52	0.251
HSTS (mm)	11.62 ± 0.49	11.65 ± 0.54	11.65 ± 0.43	0.918
HCSW (mm)	0.11 (0.08, 0.14)	0.19 (0.18, 0.22)	0.32 (0.28, 0.39)	< 0.001[abc]

NSG: narrow ciliary sulcus width group; MSG: medium ciliary sulcus width group; WSG: wide ciliary sulcus width group; SE: spherical equivalent; AL: axial length; LT: lens thickness; HWTW: horizontal white to white; ACD: anterior chamber depth; ACA: anterior chamber angle; ACV: anterior chamber volume; HATA: horizontal ATA; HSTS: horizontal STS; HCSW: horizontal ciliary sulcus width

[a] *P* < 0.001 for the difference between NSG and MSG

[b] *P* < 0.001 for the difference between NSG and WSG

[c] *P* < 0.001 for the difference between MSG and WSG

Table 3 Correlation analysis between HCLR/HSTSL and vault at 1 month for the three HCSW groups

Groups	Eyes	Vault at 1 month (μm)		HCLR (mm)	HSTSL (mm)
TOTAL	223	590.51 ± 218.24	r	-0.310	-0.345
			P	< 0.001	< 0.001
NSG	89	619.54 ± 214.26	r	-0.451	-0.420
			P	< 0.001	< 0.001
MSG	73	561.21 ± 234.00	r	-0.267	-0.311
			P	0.023	0.007
WSG	61	583.21 ± 202.09	r	-0.225	-0.316
			P	0.081	0.013

NSG: narrow ciliary sulcus width group (HCSW ≤ 0.150 mm); MSG: medium ciliary sulcus width group (0.150 mm < HCSW ≤ 0.250 mm); WSG: wide ciliary sulcus width group (HCSW > 0.250 mm); HCLR: horizontal CLR; HSTSL: horizontal STSL

pole. What is noteworthy is that we noticed that overall (VSTSL - HSTSL) is larger than (VCLR - HCLR), which means that the height difference between VSTS and HSTS planes is larger than the height difference between VATA and HATA planes. This further highlights the distinction between the anterior and posterior chambers [20]. Based on the anatomy the main thing between the anterior chamber angle and the ciliary process is the iris and the ciliary sulcus; several studies have shown that there is no significant difference in the thickness of the iris root both horizontally and vertically [21, 22], so it is reasonable to suspect that it is the morphology of the ciliary sulcus that is responsible for this difference. Our study showed that VCSW is larger than HCSW, which somehow may explain the relationship between (VSTSL - HSTS) and (VCLR - HCLR). However, additional study is required.

Our study showed that both CLR/STSL were correlated with ACV, ACA, LT, and ACD, which is consistent with some studies that found that LT increases with age, which in turn leads to a shallowing of ACD, decrease of ACA, and decreasing of ACV [7, 23]. The results of such correlations are not uniform due to individual differences. Consistent with the study of Fan et al. [11], this study also found that only HCLR was negatively correlated with AL. We believe that the correlation between STSL and AL diminishes due to the influence of the ciliary sulcus morphology on STSL measurements.

Recently, more and more surgeons have realized that the morphology of the ciliary body plays a crucial role in vault. To date, there are fewer reports in the literature on CSW. Ye et al. [14] introduced CSW into ICL implantation in a study exploring ciliary sulcus morphology and ICL haptics location in eyes with the low vault. CSW and STS are both length parameters in the vicinity of the ciliary sulcus and are therefore equivalent in terms of measurement difficulty. The reliability and reproducibility of UBM have previously been considered to be poor, and it has been suggested that fixation of the examiner could effectively avoid such situations [24]. The UBM examination in this study was performed by the same examiner, and the CSW results of our measurements were

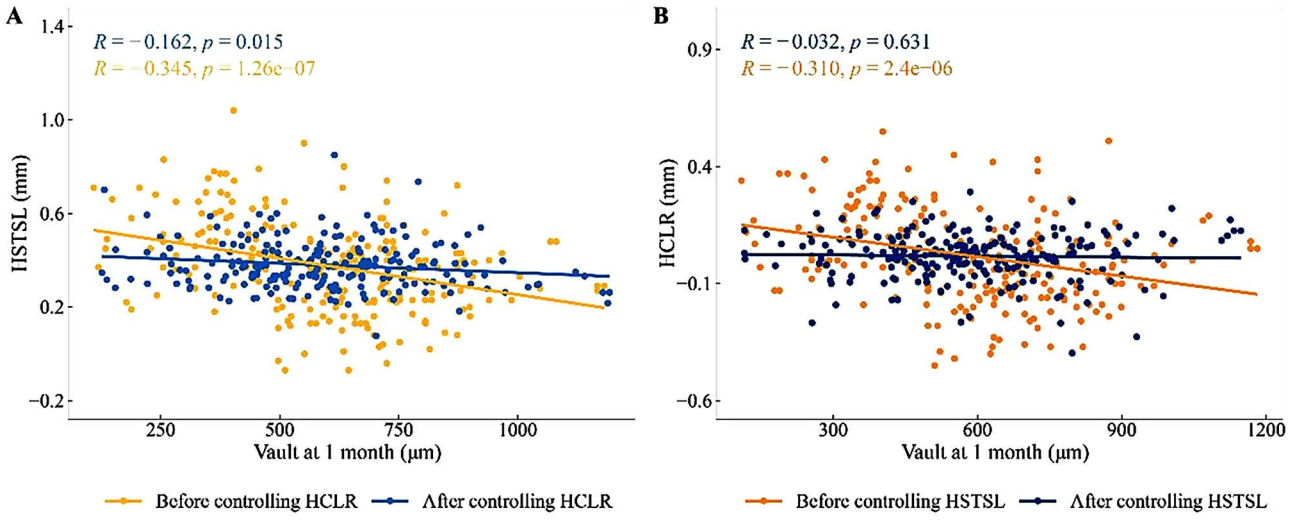

Fig. 3 Partial correlation analysis between HCLR/HSTSL and vault at 1 month. The association between HCLR/HSTSL and vault was further explored in all eyes by partial correlation analysis. HCLR: horizontal CLR; HSTSL: horizontal STSL

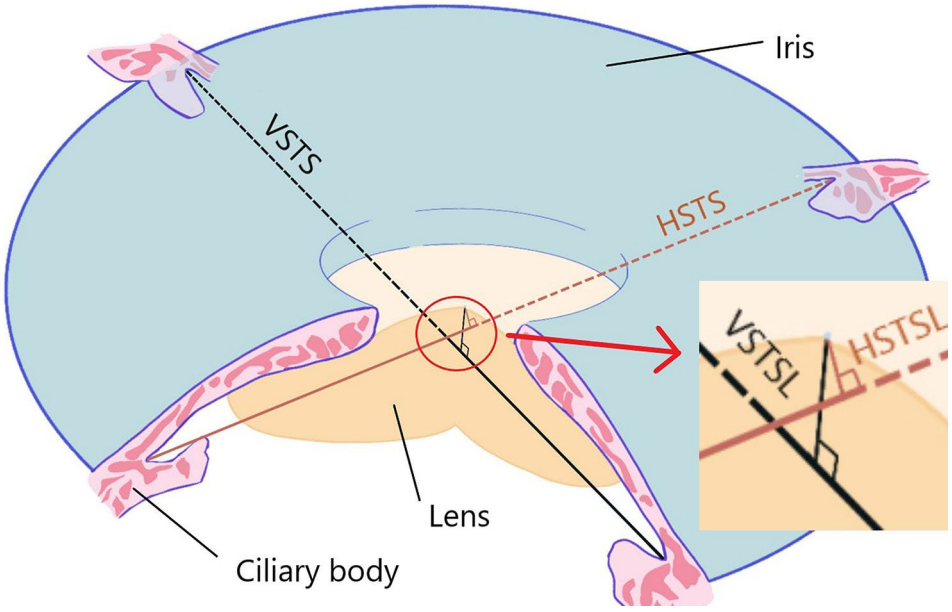

Fig. 4 Indicates that the two ciliary sulcus connecting lines are located in different coronal planes and are more posterior vertically than horizontally. VSTS, vertical STS; HSTS, horizontal STS; VSTSL, vertical STSL; HSTSL, horizontal STSL

consistent with Ye et al. [14] and Nils et al. [25]. Therefore, we consider the CSW results to be reliable in our study. Recently Li et al. [26] suggested that a standardized protocol can be effective in improving intra-examiner reliability and inter-examiner agreement, which may help to improve our examination process in the future. To better interpret the results of Table 3, it is essential to introduce some new measurement parameters. Vault can be disassembled by the concepts of the ICL arc (the difference in height between the highest point of the posterior surface of the ICL crystal and the lowest point of the ICL haptics) and the lens arc (the difference in height from the highest point of the anterior surface of the lens to the lowest point of the ICL haptics) proposed by Tan et al. [27]. Vault is to some extent the difference between the ICL arc and the lens arc. The ICL arc is the arch shape formed by the ICL in the eye which is mostly created by ciliary processes compressing the ICL haptics horizontally and the iris' downward pressure on the ICL [12]. The accurate prediction of the lens arc as a percentage of the ICL arc is key to predicting postoperative vault, and STSL and CLR have been used as a proxy for the lens arc.

More and more studies are finding that ICL haptics are not always located in the ciliary sulcus and that

numerous factors influence the location of the haptics. Roger et al. [28] examined 52 eyes with successful ICL implantation and found that in 81% (42 eyes) of cases, the ICL haptics were not in the ciliary sulcus on both the temporal and nasal sides. Dislocation of the ICL haptics results in changes in the ICL arc and the lens arc, causing the STSL/CLR to not accurately represent the lens arc and ultimately affecting the correlation of the STSL/CLR with vault [29]. Ye et al. [14] found that the incidence of the high vault is increased when CSW is narrow or even absent because at this time most of the ICL haptics are located in the ciliary sulcus with less possibility of sliding. Similar results were obtained by Chen et al. [30] and Peng et al. [13]. According to the findings, we think that in NSG and MSG, HSTSL can effectively indicate the ratio of the lens arc in the ICL arc due to the majority of ICL haptics being situated in the ciliary sulcus. In this situation, the correlation between HCLR and vault still exists, because HCLR, although not representative of the whole the lens arc, reflects the lens arc in a certain proportion. Therefore, we believe that because of the convenience of CLR measurements, CLR can temporarily replace STSL when CSW is small. On the other hand, in WSG, the ICL haptics are displaced to a higher extent or even inserted below the ciliary processes [14, 27, 31]. In addition, CLR is an ATA-based lens height that does not reflect the posterior chamber structure. The tenuous proportionality of CLR to the lens arc is difficult to maintain in WSG, and then it makes sense that the correlation between HCLR and vault disappears. On the contrary, because STSL takes into account the ciliary sulcus morphology, it reflects the lens arc more accurately than CLR, so the correlation with vault remains in WSG. When CSW exceeds 0.250 mm, CLR ceases to be a reliable predictor of postoperative vault, and STSL results become especially valuable for determining the crystal selection of ICL. In our study, the correlation coefficient between STSL and vault in NSG is for the largest of the three groups, and we suspect that there will be changes in other parameters during the process of CSW enlargement so that the position of the ICL haptics will be influenced by multiple factors. Our speculation is once again supported by the study of Ye et al. [14] who found that in addition to CSW, trabecular–ciliary angle (TCA), iris–ciliary angle (ICA), ciliary process length (CPL), and maximum ciliary body thickness (CBTmax) also correlated with ICL haptics location. In addition, the results with biased correlation indirectly suggest that the effect of CLR on vault may originate from STSL, which is exactly in line with the fact that compared to STSL, CLR represents only the tip of the iceberg of the lens arc. The question of the correlation between the two lens heights and vault comes down to the position of the ICL haptics affecting the lens arc, it is key to be able to accurately predict the position of the haptics.

With the development of science and the updating of equipment, AS-OCT is widely used in clinical practice because of the advantages of non-contact, patient compliance, and reliable results [18]. ANTERION as an advanced AS-OCT can perform wider and deeper scans, and Kim et al. [32] established the ICL vault prediction and ICL size model based on it. li et al. [33] studied the changes in the anterior segment of the eye caused by different luminance lights after ICL implantation using AS-OCT. However, AS-OCT has poor penetration compared to UBM. The posterior pigmented layer of the iris and sclera prevents the passage of infrared light from AS-OCT, rendering the ciliary body and suprachoroidal space invisible [34]. Qian et al. [35] in their study of inflammatory glaucoma found that UBM had a significant advantage over AS-OCT in visualizing the ciliary body and peripheral iris. Lincke et al. [36] found that ciliary body length (CBL) measured by AS-OCT was shortened by 2 mm compared to the true value, which they attributed to the ability of AS-OCT to poorly image posterior chamber structures. It can be seen that UBM is still superior to AS-OCT in ciliary imaging [15]. As AS-OCT has greater repeatability and accuracy, combining these two devices to study the structure of the anterior segment of the eye in the future will make the results more reliable.

The STAAR online calculation directs ICL sizing based on ACD and HWTW only, but more and more other relevant parameters are now being determined. CLR and STSL, in this study, are important components of the NK formula [37] and Reinstein's formula [6]. Ando et al. [38] showed that the NK formula predicts vault significantly more than the actual value. Based on the results of our study, it is reasonable to suspect that CSW may have caused a bias in the NK formula and thus contributed to this result. Clarifying whether CSW affects the accuracy of ICL crystal size selection formulas (e.g., the NK formula) that include the independent variable CLR would further support our conclusions.

Our study had several limitations. Firstly, the accuracy of the relevant parameters obtained by UBM is affected by anthropogenic factors [39] and needs to be further validated. Second, only highly myopic populations in southern China were included. Due to the differences in ciliary body morphology between races [40] and the refractive status of populations in northern and southern China [41], the universality of our findings should be investigated. Thirdly, the relatively small sample size and short follow-up period of this study make it worthwhile to conduct large-sample, multicentre clinical trials in the future. Fourth, the mean AL in this study was approximately 27 mm, and whether this conclusion applies to all

ranges of AL (especially AL>28 mm [42]), needs to be further verified in future studies.

Conclusions

Our study suggests that more emphasis ought to be placed on STSL when determining ICL crystal size preoperatively because it more accurately reflects the lens arc than CLR; and STSL is the second parameter, after the CLR, that is not uniformly distributed horizontally and vertically. Clinicians should pay attention to these which may help to improve the optimal vault rate.

Abbreviations

ICL	Implantable collamer lens
CLR	Crystal lens rise
STSL	The distance between STS plane and the anterior crystalline lens surface
UBM	Ultrasound biomicroscopy
CSW	Ciliary sulcus width
ACD	Anterior chamber depth
UDVA	Uncorrected distance visual acuity
CDVA	Corrected distance visual acuity
IOP	Intraocular pressure
ECD	Corneal endothelial cell density
HWTW	Horizontal white to white
ACV	Anterior chamber volume
ACA	Anterior chamber angle
LT	Lens thickness
AL	Axial length
STS	Distance of ciliary sulcus-to-sulcus
ATA	Distance of angle-to-angle
H/V	Horizontal/Vertical direction
NSG	Narrow ciliary sulcus width group
MSG	Medium ciliary sulcus width group
WSG	Wide ciliary sulcus width group
AS-OCT	Anterior segment optical coherence tomography
VSTSL - HSTSL	The difference between VSTSL and HSTSL
VCLR - HCLR	The difference between VCLR and HCLR
The ICL arc	The difference in height between the highest point of the posterior surface of the ICL crystal and the lowest point of the ICL haptics
The lens arc	The difference in height from the highest point of the anterior surface of the lens to the lowest point of the ICL haptics
TCA	Trabecular–ciliary angle
ICA	Iris–ciliary angle
CPL	Ciliary process length
CBTmax	Maximum ciliary body thickness

Supplementary Information

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Supplementary Material 1

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None.

Author contributions

YJN and TS were involved in the design and conduct of the study and were major contributors to writing the manuscript; HHJ and KLZ collected the data and helped in designing tables and figures; YD and YPW collected the data and provided statistical analysis; TS and PJQ critically revised the manuscript; PJQ and CYH offered financial and technical support; All authors read and approved the final manuscript.

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Data availability

All data used or analyzed during this study are available from the corresponding author upon reasonable request. Data is provided within the manuscript or supplementary information files.

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 the Second Affiliated Hospital of Zhejiang University School of Medicine. (NO: IR2023454). 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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