Determinants of intraocular lens tilt and decentration after cataract surgery

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Background: To identify the main determinants of intraocular lens (IOL) tilt and decentration after cataract surgery using a novel anterior segment optical coherence tomography (AS-OCT) method.

Methods: Fifty-six patients who underwent phacoemulsification with IOL implantation in one eye were continuously enrolled in this cohort study. Axial length (AL) was measured with IOL Master 700. The tilt and decentration of patients' preoperative crystalline lenses and postoperative IOLs, as well as crystalline lens thickness (LT), were measured using AS-OCT before surgery and 1 week after surgery.

Results: The mean tilt and decentration of the patients' preoperative crystalline lenses were 4.90°±1.81° and 0.21±0.02 mm, and the mean tilt and decentration of IOLs were 4.75°±1.66° and 0.21±0.02 mm, respectively. There were no significant differences in magnitude, direction of tilt, or decentration between crystalline lenses and IOLs. The strongest determinant of IOL tilt was preoperative crystalline lens tilt (R^2=0.512, P<0.001), followed by AL (R^2=0.154, P=0.003). Additionally, crystalline lens decentration and AL explained 54.6% of the variability in IOL decentration. AL was the factor most highly associated with IOL decentration (R^2=0.332, P<0.001), rather than crystalline lens decentration (R^2=0.214, P<0.001).

Conclusions: The position of the preoperative crystalline lens and AL were the critical determinants of IOL tilt and decentration. The tilt and decentration of IOLs will be greater in patients with larger tilt and decentration of crystalline lenses, or shorter and longer AL.

Keywords: Crystalline lenses; intraocular lens (IOL); tilt; decentration; axial length (AL)

Introduction

Misalignment of the intraocular lens (IOL) is an important risk factor for the deterioration of visual quality after cataract surgery. Previous studies have found that an IOL tilt greater than 7° or decentration greater than 0.4 mm affects visual quality after IOL implantation by increasing wavefront aberrations, such as astigmatism and high-order aberrations (HOA) (1-3). Especially for toric and multifocal IOLs, their optical performances were more sensitive to tilt and decentration. Tilt and decentration may cause fewer predictable astigmatisms for toric IOLs and induce larger comas for multifocal IOLs (4-7). To achieve better postoperative visual quality, it is necessary to understand the main factors that contribute to IOL tilt and decentration after cataract surgery.

Scheimpflug photography, Purkinje images, and anterior segment optical coherence tomography (AS-OCT) have

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been used in the past to measure the tilt and decentration of IOLs (8-13). However, none of the above methods can measure the tilt and decentration of crystalline lenses and IOLs automatically, which need to be combined using image processing software. The accuracy and repeatability of measurements therefore depend on the alignment and quality of images. CASIA2, a novel second generation of AS-OCT, has been demonstrated to measure the tilt and decentration of crystalline lenses and IOLs automatically and quantitatively with high repeatability (14). It can clearly outline the crystalline lens or IOL and generate three-dimensional (3D) results of tilt and decentration using the visual line as a reference. Compared with the pupil center, the visual line is considered a better reference for assessing IOL tilt and decentration, because it is not affected by the shape of the pupil.

Although several studies have found that the magnitude and direction of tilt of postoperative IOLs were correlated with the tilt of preoperative crystalline lenses, these results were inconsistent (15,16). Hirnschall *et al.* reported that the tilt directions of crystalline lenses and IOLs were strongly correlated, while their magnitudes of tilt were more weakly correlated (15). Wang *et al.* demonstrated that preoperative crystalline lens tilt was strongly correlated with IOL tilt (r=0.707) (16). Moreover, axial length (AL) may be another critical factor that affects the tilt and decentration of crystalline lenses and IOLs. A greater tilt of both crystalline lenses and IOLs has been reported to be associated with shorter AL (16). Furthermore, anterior chamber depth (ACD) and lens thickness (LT) have also been found to be negatively correlated with crystalline lens tilt (16). However, whether crystalline lens decentration is associated with IOL decentration has yet to be established.

In this study, we measured the tilt and decentration of patients' crystalline lenses and IOLs before and after cataract surgery using CASIA2 and then analyzed their characteristics, identifying the main determinants of IOL tilt and decentration following phacoemulsification with IOL implantation. We present the following article in accordance with the STROBE reporting checklist (available at http://dx.doi.org/10.21037/atm-20-1008).

Methods

Study population and design

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). This prospective cohort study was approved by the Institutional Review Board of Zhongshan Ophthalmic Center in Sun Yat-Sen University (Guangzhou, China) (NO.: 2019 KYPJ033) and informed consent was obtained from all patients. A total of 56 patients (56 eyes) that planned to undergo phacoemulsification with IOL implantation between August and September, 2019, at Zhongshan Ophthalmic Center were continuously recruited in this study. Patients with the following conditions were excluded: (I) ocular disease that may affect the function of the suspensory ligament of lens, such as previous ocular trauma, lens subluxation, pseudoexfoliation, or retinal pigment degeneration; (II) previous intraocular surgery; or (III) intraoperative or postoperative complications.

General examinations

Patient data, including age, gender, and medical history, were obtained from the patients' medical records. AL was measured using IOL Master 700 (Carl Zeiss, Meditec, Dublin, CA, USA) in a dark room following anterior slit-lamp biomicroscopy examination. Nuclear opacities and cortical opacities were graded by two ophthalmologists (XY-C and XX-G) according to the Lens Opacities Classification System III (LOCS III).

AS-OCT examination

All subjects underwent anterior segment imaging before and 1 week after cataract phacoemulsification with IOL implantation surgery using CASIA2 (TOMEY, Japan) under non-mydriatic conditions. Crystalline lenses and IOLs were measured using the Lens Biometry and IOL Scan modes, respectively. Using the Lens Biometry mode, CASIA2 generated 16 distinct AS-OCT images from 16 different angles of each patient's crystalline lens (0–180, 11–191, 23–203, 4–214, 45–225, 56–236, 68–248, 79–259, 90–270, 101–281, 113–293, 124–304, 135–315, 146–326, 158–338, and 169–349). Using the IOL Scan mode, 8 distinct AS-OCT images from 8 different angles (0–180, 90–270, 23–203, 113–293, 45–225, 135–315, 68–248, and 158–338) were obtained. The outlines of the crystalline lenses and IOLs were automatically recognized and 3D analyses of tilt and decentration were directly generated by built-in software (Version SS2000) relative to the visual line. The same examiner checked and adjusted the crystalline lens and IOL outlines to ensure tilt and decentration were measured accurately. Examples of 3D results from a crystalline lens
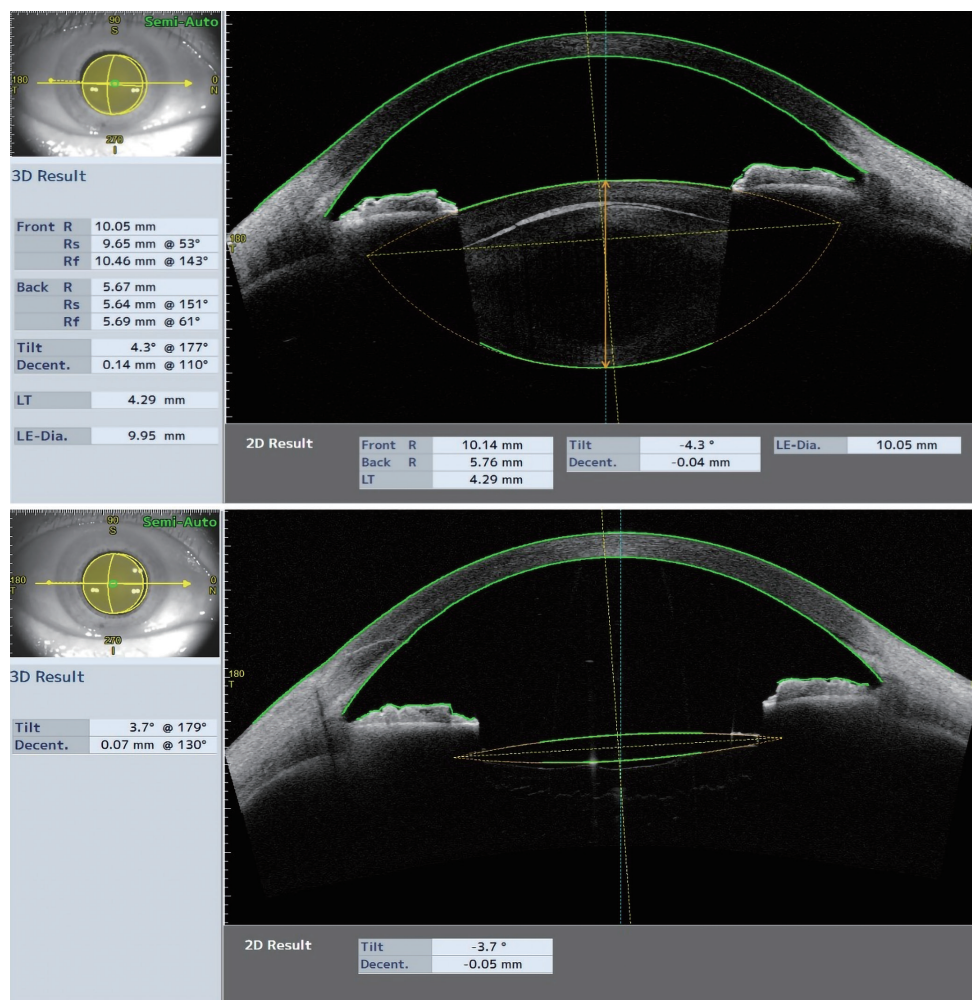
Figure 1 These representative images show the 3D results of a crystalline lens and an IOL. The optic axis of the IOL (yellow dotted line) and the visual line (blue dotted line) were automatically generated by built-in software. IOL, intraocular lens; R, radius of curvature, Front R, radius of curvature for the lens front surface; Rs, steep radius of curvature; Rf, flat radius of curvature; Back R, radius of curvature for the lens back surface; Decent., decentration; LT, lens thickness (thickness of the crystalline lens); LE-Dia., lens equatorial diameter (equatorial diameter of the crystalline lens).

and an IOL are shown in *Figure 1*.

Surgical techniques

All subjects underwent cataract phacoemulsification with IOL implantation surgery after receiving local anesthesia. Each patient received a 2.2 mm temporal corneal incision that was self-sealing. After continuous circular capsulorhexis and cataract phacoemulsification, the patients were implanted with a one-piece hydrophobic IOL (SN60WF, Alcon Laboratories, Texas, USA). All surgeries were performed by two experienced ophthalmologists (YZ-L and

LX-L).

Statistical analysis

All statistical analyses were carried out with StataSE15 (version 15.0, Stata Corp LP, TX, USA). All continuous variables were expressed as mean ± standard deviation. Categorical variables were expressed as counts and percentages. A paired-sample t-test was performed to assess tilt and decentration differences between preoperative crystalline lenses and postoperative IOLs. Univariate and multivariate regression analyses were used to determine the

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Table 1 Participant characteristics

Characteristic	Value
Patients, n	56
Age (yrs.), mean (SD)	69.25 (10.81)
Male, n (%)	21 (37.5)
Female, n (%)	35 (62.5)
Diabetes, n (%)	15 (26.79)
Hypertension, n (%)	20 (35.71)
Nuclear opacity grading score, mean (SD)	3.51 (0.86)
Cortical opacity grading score, mean (SD)	3.20 (0.92)
Lens thickness (mm), mean (SD)	4.51 (0.48)
Axial length (mm), mean (SD)	24.27 (2.25)
Axial length ≥26 mm, n (%)	9 (16.07)
Cataract types, n (%)	
Age-related cataract	47 (83.93)
Complicated cataract	9 (16.07)

Table 2 The tilt and decentration of preoperative crystalline lenses and postoperative IOLs

	Tilt, degree (°)	Decentration (mm)
Crystalline lenses	4.90±1.81	0.21±0.02
IOLs	4.75±1.66	0.21±0.02
P value	0.507	0.978

IOL, intraocular lens.

correlation of IOL tilt and decentration with preoperative crystalline lenses tilt and decentration, age, gender, presence of diabetes mellitus, AL, and LT. A P value <0.05 was considered statistically significant.

Results

Patients

A total of 56 patients (56 eyes) who finished preoperative and postoperative examinations (1 week after surgery) were recruited in this study. The mean age was 69.25±10.81 years with a range of 28 to 91 years, and 62.5% of the participants were women. The mean AL was 24.27±2.25 mm with a range of 21.38 to 32.27 mm. The basic characteristics of the patients are shown in *Table 1*.

Tilt and decentration of preoperative crystalline lenses and postoperative IOLs

Table 2 shows the mean values of the tilt and decentration of preoperative crystalline lenses and postoperative IOLs relative to the visual line. For the crystalline lenses, the mean magnitude of tilt was 4.90°±1.81° and the mean decentration was 0.21±0.02 mm under non-mydriatic conditions. For the IOLs, the mean magnitude of tilt was 4.75°±1.66° and the mean decentration was 0.21±0.02 mm. No significant difference existed in magnitude of tilt or decentration between preoperative crystalline lenses and postoperative IOLs (P=0.507 and P=0.978, respectively).

As illustrated in *Figure 2*, preoperative crystalline lenses and postoperative IOLs were both tilted toward the inferotemporal direction in the right and left eyes. Although the directions of decentration were relatively scattered, more crystalline lenses and IOLs were decentered towards the temporal direction. Additionally, the directions of tilt and decentration for crystalline lenses and IOLs were found to be essentially the same.

Determinants of IOL tilt and decentration

Table 3 shows the univariate and multivariate regression analysis results for IOL tilt and decentration. In the univariate analysis of IOL tilt, the tilt of preoperative crystalline lenses alone had the highest determinate coefficient (R^2=0.512, P<0.001), followed by AL (R^2=0.154, P=0.003). In the multivariate analysis, a greater IOL tilt was significantly associated with a greater preoperative crystalline lens tilt (P<0.001), thicker lens (P=0.011), and a shorter AL (P=0.033) (*Figure 3A*). Age, sex, and the presence of diabetes were not significantly associated with IOL tilt. Of the 5 patients with a tilt greater than 7°, 4 also had a crystalline lens tilt greater than 7° before surgery and their average AL (22.82±0.98 mm) was shorter than the overall mean AL (24.27±2.25). These findings indicated that preoperative crystalline lens tilt and shorter ALs were the main determinants of postoperative IOL tilt.

AL was the factor most highly associated with IOL decentration (R^2=0.332, P<0.001), rather than preoperative crystalline lens decentration (R^2=0.214, P<0.001). AL and crystalline lens decentration explained 54.6% of the variability in IOL decentration. Greater IOL decentration was dramatically associated with longer AL (P<0.001) and greater decentration of preoperative crystalline lenses (P<0.001) (*Figure 3B*). No correlation existed between IOL
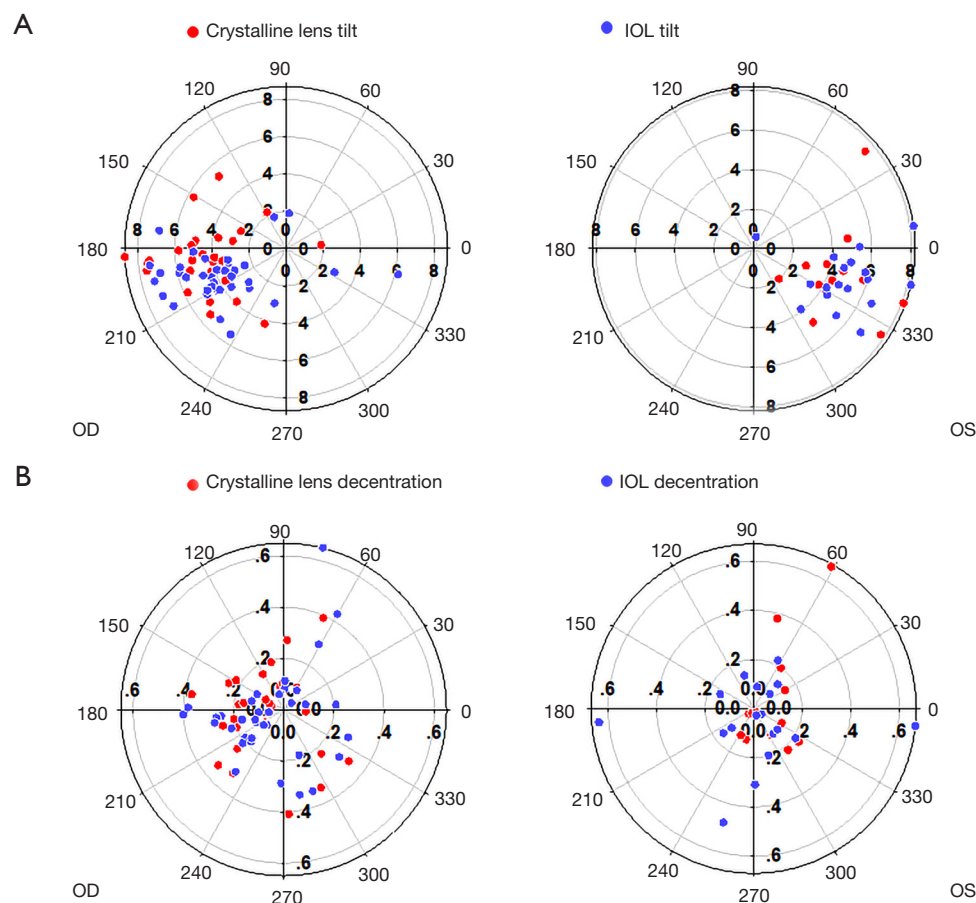
Figure 2 The distributions of tilt and decentration of IOL and crystalline lens in both eyes. (A) Coordinate graphics showing the orientations and values of crystalline lens and IOL tilt in the right (OD: oculus dextrus) and left (OS: oculus sinister) eyes. Preoperative crystalline lenses and IOLs both tilted towards the inferotemporal direction in both eyes (red circle: crystalline lens; blue circle: IOL; OD: n=38, OS: n=18); (B) coordinate graphics showing the orientations and values of crystalline lens and IOL decentration in the right and left eyes. Crystalline lenses and IOLs were both more likely to decenter towards the temporal direction (red circle: crystalline lens; blue circle: IOL; OD: n=38, OS: n=18). IOL, intraocular lens.

decentration and age, gender, the presence of diabetes, or LT. Of the 6 patients with a decentration greater than 0.4 mm, 4 had an AL longer than 29 mm, and the remaining 2 patients already had a crystalline lens decentration greater than 0.4 mm before surgery. These results suggested that IOL decentration is greater in cataract patients with longer ALs and greater decentration of preoperative crystalline lenses.

Discussion

Large misalignments of IOLs can result in the deterioration of postoperative visual quality in pseudophakic patients (17). Previous studies have demonstrated that preoperative crystalline lens tilt can predict postoperative IOL tilt (15). In the current study, using a novel AS-OCT CASIA2 method, we found that preoperative crystalline lenses and postoperative IOLs both tended to tilt approximately 5° towards the inferotemporal direction and shifted 0.21 mm towards the temporal direction. The directions of tilt and decentration for crystalline lenses and IOLs were almost the same. Additionally, greater IOL tilt was significantly associated with greater preoperative crystalline lens tilt, thicker lenses, and shorter ALs. Preoperative crystalline lens tilt was the strongest determinant of IOL tilt, followed by AL. Moreover, we

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Table 3 Univariate and multivariate analyses of the associations between the tilt and decentration of IOLs and the systemic and ocular parameters

Variables	Univariate analysis			Multivariate analysis	
	Regression coefficient (95% CI)	R^2	P	Regression coefficient (95% CI)	P
IOL tilt					
Age (yrs.)	0.046 (0.006 to 0.087)	0.091	0.968	0.016 (–0.022 to 0.053)	0.407
Gender (female)	–0.671(–1.593 to 0.250)	0.039	0.250	–0.324 (–1.012 to 0.365)	0.349
Diabetes (yes)	–0.147 (–1.184 to 0.890)	0.002	0.777	–0.222 (–0.942 to 0.498)	0.538
Preoperative lens tilt (°)	0.658 (0.481 to 0.835)	0.512	<0.001	0.565 (0.374 to 0.756)	<0.001
Lens thickness (mm)	–0.258 (–1.192 to 0.676)	0.006	0.582	–1.009 (–1.772 to 0.246)	0.011
Axial length (mm)	–0.286 (–0.469 to –0.102)	0.154	0.003	–0.173 (–0.332 to –0.014)	0.033
IOL decentration					
Age (yrs.)	–0.003 (–0.007 to 0.001)	0.051	0.098	–0.002(–0.005 to 0.002)	0.375
Gender (female)	0.024 (–0.061 to 0.110)	0.006	0.570	–0.023 (–0.086 to 0.041)	0.480
Diabetes (yes)	–0.072 (–0.165 to 0.020)	0.044	0.124	0.015 (–0.054 to 0.083)	0.668
Preoperative lens decentration (mm)	0.541(0.249 to 0.833)	0.214	<0.001	0.620 (0.383 to 0.857)	<0.001
Lens thickness (mm)	–0.074 (–0.157 to 0.009)	0.057	0.079	0.029 (–0.043 to 0.101)	0.423
Axial length (mm)	0.038 (0.023 to 0.053)	0.332	<0.001	0.041 (0.026 to 0.055)	<0.001
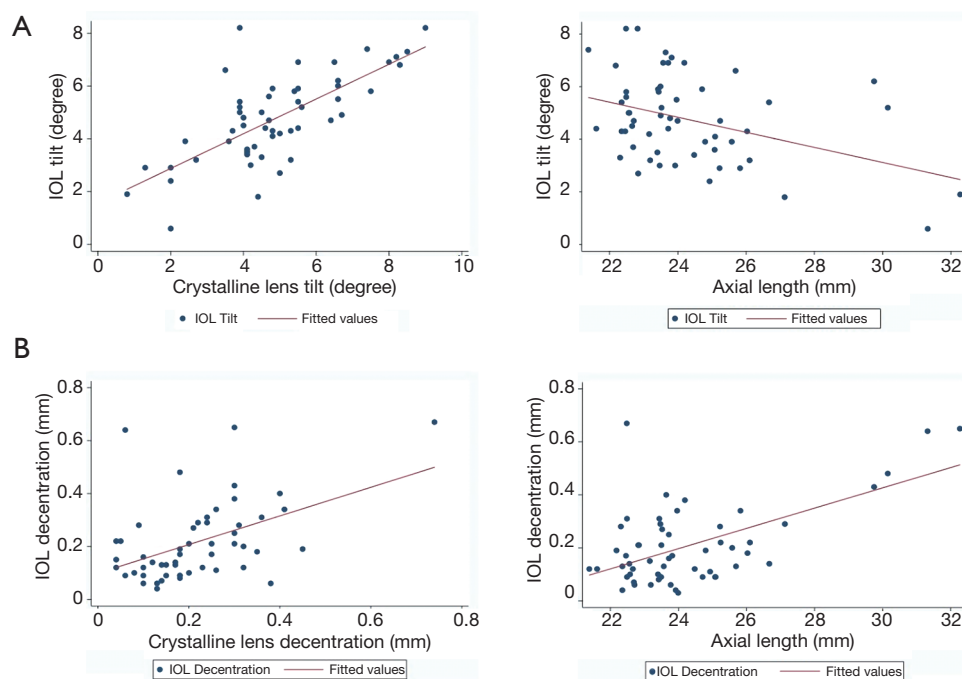
Figure 3 Correlations between the tilt and decentration of IOL with crystalline lens position and axial length. (A) Scattergrams showing the relationships between preoperative crystalline lens tilt and IOL tilt, as well as AL and IOL tilt; (B) scatter grams showing the relationships between preoperative crystalline lens decentration and IOL decentration, as well as AL and IOL decentration. IOL, intraocular lens; AL, axial length.

demonstrated for the first time that AL and preoperative crystalline lens decentration were the two most important factors in determining IOL decentration.

Several studies have previously reported that the mean tilt of normal crystalline lenses ranged from 2.85° to 4.6° using magnetic resonance imaging (MRI) or Purkinje images (18-20). Chang *et al.* reported that crystalline lens tilt was 3.7°±2.5° for the anterior surface and 3.3°±1.4° for the posterior surface, while the horizontal decentration of crystalline lenses was 0.11±0.07 mm and the vertical decentration was 0.06±0.38 mm relative to the corneal axis using MRI 3D-image reconstruction (18). Schaeffel *et al.* found using Purkinje images that all natural lenses tilted about 4.6° toward the temporal side and decentered approximately 0.3 mm downward relative to the pupil center (19). Findings in another study showed that crystalline lenses decentered 0.25 mm toward the temporal direction and tilted 2.85° toward the inferotemporal direction (20). Kimura *et al.* were the first to use a second generation AS-OCT (CASIA2, TOMEY) to measure the tilt and decentration of crystalline lenses and IOLs. They found that both crystalline lenses and IOLs had inferotemporal tilts of 4.22–5.30° and temporal decentration of 0.03–0.12 mm (14). The magnitude of tilt and decentration of crystalline lenses and IOLs in our study were greater than that found by some previous studies. We believe the primary reason for this is that the patients enrolled in our study had a greater AL range, being 21.38 to 32.27 mm.

More than 10 years ago, Hu *et al.* hypothesized that IOL misalignment might be caused by malposition of the crystalline lens (20). In recent years, several studies have reported the relationship between the tilt of crystalline lenses and that of IOLs. Hirnschall *et al.* reported that the mean tilts of crystalline lenses and IOLs were 4.3° and 6.2°, respectively, using IOL Master 700. A strong correlation was found between the tilt direction of crystalline lenses and that of IOLs (r=0.71), whereas there was a weaker correlation between their magnitudes of tilt (r=0.39) (15). In a larger sample study, Wang *et al.* found a stronger correlation between preoperative crystalline lens tilt and postoperative IOL tilt (r=0.707) (16). Using CASIA2, we found the mean tilt of crystalline lenses to be 4.9° and the mean tilt of IOLs to be 4.75°, and the tilt of crystalline lenses explained 51.2% of the variability in IOL tilt. These measurements were within the range of previous findings.

However, the correlation between preoperative crystalline lens decentration and that of postoperative IOLs is unclear. In the current study, we found a clear correlation between preoperative crystalline lens decentration and postoperative IOL decentration (R^2=0.214, P<0.001), but this correlation was weaker than that found for tilt. Interestingly, AL, rather than preoperative crystalline lens decentration, was the factor most highly associated with IOL decentration (R^2=0.332, P<0.001). Greater IOL decentration was dramatically associated with longer AL. A possible explanation is that IOLs are more likely to shift in the loose lens capsular bags of eyes with long ALs. Furthermore, we found that AL was negatively correlated with IOL tilt. This result is consistent with that of a previous study (16). IOLs are therefore more prone to tilt in patients with short ALs. Therefore, the use of toric or multifocal IOLs should be appropriate for cataract patients with long or short ALs.

Our study had some limitations. Firstly, the number of participants was small, meaning the relevance of tilt and decentration between crystalline lenses and IOLs may be underestimated. Secondly, the duration of our study was short, meaning we could not observe the long-term stability of IOLs. Therefore, large-scale and long-term studies are necessary to verify our results.

In conclusion, our study showed that preoperative crystalline lens tilt was the strongest determinant of postoperative IOL tilt, followed by AL. Greater IOL tilt was significantly associated with greater preoperative crystalline lens tilt and shorter AL. AL, rather than crystalline lens decentration, was the factor most highly associated with IOL decentration. Greater IOL decentration was dramatically associated with longer AL and greater preoperative crystalline lens decentration. These findings indicate that the tilt and decentration of postoperative IOLs are greater in patients with more tilted and decentered crystalline lenses, as well as those with shorter or longer ALs.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at http://dx.doi.org/10.21037/atm-20-1008

Data Sharing Statement: Available at http://dx.doi.org/10.21037/atm-20-1008

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at http://dx.doi.org/10.21037/atm-20-1008). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). This prospective cohort study was approved by the Institutional Review Board of Zhongshan Ophthalmic Center in Sun Yat-Sen University (Guangzhou, China) (NO.: 2019 KYPJ033) and informed consent was obtained from all patients.

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