· Clinical Research ·

Alpha and Kappa angle on postoperative visual quality in cataract surgery

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Abstract
● **AIM:** To explore the effect of Alpha angle and Kappa angle before multifocal intraocular lenses (MIOLs) implantation on postoperative visual quality of patients.
● **METHODS:** Before and 3mo after cataract surgery, Alpha angle and Kappa angle were collected using IOL Master 700, iTrace, and Pentacam for clinical observation. Postoperative visual quality indicators, including high-order aberrations (HOA), modulation transfer function (MTF) and point spread function (PSF), were collected using iTrace. multiple linear regression analysis was used to analyze the correlation of the Kappa angle and the Alpha angle with age, axial length (AL), anterior chamber depth (ACD), keratometry (K), lens thickness (LT) and corneal white to white distance (WTW). Pearson correlation coefficient was used to analyze the correlation between Alpha angle and Kappa angle; Bland Altman analysis was used to evaluate the consistency of pairwise detection results of three instruments.
● **RESULTS:** The Alpha angle was modeled as Alpha=2.230+0.003×age-0.036×AL-0.025×K-0.058×WTW and the Kappa angle was modeled as Kappa=0.685+0.003×age-0.013×K-0.061×WTW. The correlation between the total Alpha angle and Kappa angle of the three instruments was weakly positive (r=0.291, P=0.000). Comparing the measurement of Alpha angle and Kappa angle using three instruments, only IOL Master 700 and iTrace showed good consistency in measuring Kappa angle (P=0.4254). After 3mo of surgery, the Alpha angle and Kappa angle significantly decreased (P=0.011, 0.018; P=0.008, 0.036). △Kappa=1.136-0.021×AL-0.013×K. Kappa angle could positively predict HOA (β=0.18, P=0.000), MTF (β=0.171, P=0.000), PSF (β=0.088, P=0.000), Alpha angle cannot (P>0.05).
● **CONCLUSION:** The patients with older age, flatter K and shorter WTW should be alert to the possibility of larger Alpha angle and Kappa angle. Alpha angle should also consider the factor of AL. When selecting patients with MIOLs implantation, there is no need to consider the Alpha angle. Careful consideration should be given to the Kappa angle, and the preoperative standard of <0.5 mm can refer to △Kappa=1.136-0.021×AL-0.013×K and be appropriately relaxed.
● **KEYWORDS:** kappa angle; alpha angle; postoperative visual quality; cataract surgery; ocular biometric instruments
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INTRODUCTION
Currently, cataract remain the leading cause of blindness in low- and middle-income countries. Several large-scale population studies have reported that the incidence of cataract is positively correlated with age, increasing from 3.9% among individuals aged 55-64 to 92.6% among those aged 80 and above, and the age group of cataract patients is gradually moving towards younger age groups[1]. Cataract surgery, as the most common surgical method in ophthalmology, has achieved rapid development in nearly half a century, going through three stages: intracapsular cataract extraction, extracapsular cataract extraction, and phacoemulsification. In the past, cataract surgery required a large incision (about 10-12 mm), resulting in high astigmatism and long recovery time for patients after surgery, and the effect was not satisfactory; As the mainstream modern cataract surgery, phacoemulsification combined with intraocular lens implantation has a small surgical incision (about 2-3 mm), and most patients have a fast visual recovery, good visual effects, and few complications[2].

In recent years, with the increasingly advanced technology of intraocular lens and the improvement of people's quality of life, the demand for surgical effect has also become higher. Today, cataract surgery is no longer just a simple requirement for visual restoration surgery, but also needs to meet the needs of patients' daily life and visual quality, entering the era of refractive cataract surgery with clear, comfortable, and long-lasting vision[3]. Therefore, to satisfy patients' increasing demands for visual quality satisfaction, it is particularly important to improve visual quality after cataract surgery as much as possible.

In the past, intraocular lenses could only correct myopia and hyperopia, while astigmatism and presbyopia required postoperative glasses correction. With the increasing accuracy of measuring the degree of intraocular lenses and the improvement of intraocular lens technology, intraocular lenses that can correct human astigmatism and meet the needs of both distance and close vision are now available. The use of multifocal intraocular lenses (MIOLs) in refractive cataract surgery provides clear vision at near, intermediate, and far distances, while reducing or eliminating the need for reading glasses[4-5]. However, these MIOLs also have some disadvantages, such as glare and halos around bright lights, which will affect the quality of life of patients[6]. The side effects of glare, halo, and flash sensation following cataract surgery with MIOLs are influenced by several factors. Such as the design of the MIOLs[7], the pupil size[8], the contrast sensitivity[9], the spherical aberration[10] and the deviations between the optical center, the visual axis, and the pupil axis of MIOLs[11]. The optical axis is a vertical line passing through the optical center, the visual axis is the line connecting the fixation point and the fovea of the macula, and the pupil axis is an axis perpendicular to the plane of the pupil passing through the incident center of the pupil. In an ideal state, the cornea-pupil-lens is concentric and parallel, with the pupil axis equal to the optical axis. If the optical center of the MIOLs is not aligned with the pupil axis, the patient may experience glare and halo due to the diffraction of light from the MIOLs into the surrounding retina, which may lead to a loss of contrast sensitivity and reduced vision. If the pupil axis is not aligned with the visual axis, functional eccentricity may occur due to the passage of light from the outside through the paracentral ring or its edges, which may lead to ghosting and a decrease in visual quality. If the optical center of MIOLs is not aligned with the visual axis, the fact that light does not pass through the center of the intraocular crystal may affect its refractive ability and lead to a decrease in visual function. The angle between the visual axis and the pupil axis is Kappa angle and the angle between the visual axis and the optical axis is Alpha angle.

In order to ensure good postoperative visual quality for patients, it is recommended that the Kappa <0.5 mm or less than half of the diameter of the central refractive optical region of MIOLs in Expert Consensus on Clinical Application of Multifocal Intraocular Lens in China (2019)[12], but the Alpha angle is not mentioned. Qi *et al*[13] believed that when the Kappa angle is greater than 0.4 mm, it increases the occurrence of glare and halo, and when it is greater than 0.5 mm, it leads to a decrease in visual quality. However, they also proposed that there may be limitations in using preoperative Kappa angle to estimate postoperative visual quality due to changes in pupil size and shape after cataract surgery. However, there are currently no research reports on how to address this limitation in order to more accurately estimate postoperative visual quality. Wang *et al*[14] pointed out that the centrality of intraocular lenses after cataract surgery is often related to the Alpha angle, and patients with larger Alpha angle are more likely to have postoperative intraocular lens eccentricity. Hu *et al*[15] suggests that when Alpha >0.5 mm, the incidence of optical interference after implantation of MIOLs increases, but further clinical data is needed for verification. Fu *et al*[16] suggests that the Alpha angle is not related to postoperative visual quality. More and more physicians are paying attention to the impact of Alpha angle on MIOLs, but there is currently no consensus on whether to consider Alpha angle when selecting surgical patients and predicting postoperative visual quality outcomes.

To make better use of Alpha angle or Kappa angle for screening cataract patients suitable for MIOLs implantation, it is essential to have an understanding of the distribution, reliability, and stability of the two parameters in patients with cataract. In recent years, various new types of ocular biometric instruments have been updated and iterated, providing support for refractive cataract surgery. The commonly used precise ocular biometric instruments related to the refractive power of intraocular lenses in clinical practice mainly include optical biometric instrument IOL Master 700 (Zeiss, Germany), visual function analyzer iTrace (Tracey, USA), and 3D anterior section analyzer pentacam (OCULUS, Germany)[17-19]. These three can collaborate and mutually reinforce each other. The Alpha angle and Kappa angle of iTrace and Pentacam were directly obtained by calculating the distance between the corneal reflection point and the center of the pupil and cornea through the built-in algorithm of the instrument; IOL Master 700 measures the horizontal distance (Px) and vertical distance (Py) between the patients' visual axis and the center of the pupil, as well as the horizontal distance (Ix) and vertical distance (Iy) between the visual axis and the center of the cornea, and then calculates the Kappa angle [Kappa=$\sqrt{(Px^2+Py^2)}$] and Alpha angle [Alpha=$\sqrt{(Ix^2+Iy^2)}$]. ITrace can also objectively measure and reflect the overall visual quality through ray tracing technology. It can not only provide high-order aberrations (HOA), but also use modulation transfer function (MTF) and point spread function (PSF) to study and analyze the visual quality of MIOLs[20]. Therefore, in this study, these instruments were used to collect Alpha angle and Kappa angle for clinical observation and analyze their relationship with postoperative visual quality. The aim is to further explore the application scope of MIOLs and better ensure the postoperative visual quality of patients.

PARTICIPANTS AND METHODS

Ethical Approval The research followed the tenets of the Declaration of Helsinki, and that informed consent was obtained from the subjects after explanation of the nature and possible consequences of the study. Clinical Research Ethics Committee of Shenzhen People's Hospital approved the study and the approval number is LL-KY-2023046-01.

Participants This prospective non-randomized case series incorporated 148 patients (296 eyes) who underwent bilateral cataract surgery from 2023.04 to 2023.09.

Inclusion criteria: 1) Patients with bilateral cataract (most of them are age-related cataract, with a few being concurrent cataract and metabolic cataract); 2) Planned to undergo bilateral cataract surgery; 3) The best-corrected visual acuity before surgery was 0.05 or better; 4) The best-corrected visual acuity after surgery was 0.8 or better.

Exclusion criteria: 1) Patients with corneal diseases such as keratitis, corneal endothelial decompensation, and corneal scars that affect vision; 2) Patients with glaucoma, iris disease, strabismus, congenital developmental abnormalities of the eye, history of trauma, or surgical history; 3) Patients with severe preoperative lens opacity that prevented data collection; 4) Patients who had a history of wearing contact lenses within 1wk; 5) Patients who were unable to cooperate with the examination.

Methods Preoperative examination: All measurements were conducted by the same operator in the same examination environment, and all patients were natural pupil status. Utilize an international standard visual acuity chart to assess the patient's distance vision, employ a non-contact tonometer to measure intraocular pressure, conduct anterior segment examination with a slit lamp microscope, and perform posterior segment examination using B-scan ultrasonography, scanning laser optical tomography, and optical coherence tomography. Each patient's eyes were examined with the IOL Master 700 (Zeiss, Germany), iTrace (Tracey, USA), and Pentacam (OCULUS, Germany) for measurements. Each eye is measured three consecutive times to obtain the average of axial length (AL), anterior chamber depth (ACD), keratometry (K), lens thickness (LT), corneal white to white distance (WTW), Alpha angle and Kappa angle.

Postoperative follow-up: After 3mo of follow-up, the postoperative Alpha angle and Kappa angle were measured again using IOL Master 700, iTrace and Pentacam. The postoperative visual quality indicators HOA, MTF and PSF were determined through iTrace.

Table 1 Description statistics of the general patient data

Parameters	*n*	Mean±SD	Percentage
Age (y)	148	66.32±10.76	-
AL (mm)	296	23.84±1.61	-
ACD (mm)	296	3.08±0.46	-
K (D)	296	44.26±1.84	-
WTW (mm)	296	11.70±0.39	-
LT (mm)	296	4.05±0.97	-
Male	62	-	41.9
Female	86	-	58.1
Smoking	33	-	22.3
Diabetes mellitus	36	-	24.3
Comorbidities	62	-	41.9

AL: Axial length; ACD: Anterior chamber depth; K: Keratometry; WTW: White to white distance; LT: Lens thickness; Min: Minimum; Max: Maximum; n: Sample size; SD: Standard deviation.

Statistical Analysis SPSS 26.0 (IBM Corporation, Armonk, NY, USA) was used to analyze the data. Measurement data are expressed as mean±standard deviation; Count data expressed in frequency and percentage. Multiple linear regression analysis was used to analyze the correlation of the Kappa angle and the Alpha angle with age, AL, ACD, K, LT and WTW. Using Pearson correlation coefficient to analyze the correlation between Alpha angle and Kappa angle (test level: α=0.05, $0.7\leq|r|<1$ indicates high correlation, $0.3\leq|r|<0.7$ indicates moderate correlation, and $|r|<0.3$ indicates low correlation). Evaluate the consistency of pairwise detection results of three instruments using Bland Altman analysis. Paired *t*-tests were used to compare Alpha angle and Kappa angle before and after surgery. Multiple linear regression was used to analyze the effects of age and ocular biometric parameters on Kappa angle changes, as well as the impact of preoperative Alpha angle and Kappa angle on postoperative visual quality. If $P<0.05$, the difference is statistically significant.

RESULTS

General Data of the Patient A total of 148 cataract patients (296 eyes), including 62 males (124 eyes) and 86 females (172 eyes), with a mean age of 66.32±10.76y, mean AL of 23.84±1.61 mm, mean ACD of 3.08±0.46 mm, mean K of 44.26±1.84 D, mean WTW of 11.70±0.39 mm and mean LT of 4.05±0.97 mm. Among them, 33 were smokers, 36 had diabetes mellitus, and 62 had comorbidities (Table 1).

Effect of Age, AL, ACD, K, WTW and LT on the Alpha and Kappa angle It indicated that there was a linear correlation between the Alpha angle and age, AL, K and WTW. The Alpha angle was modeled as Alpha=2.230+0.003×age-0.036×AL-

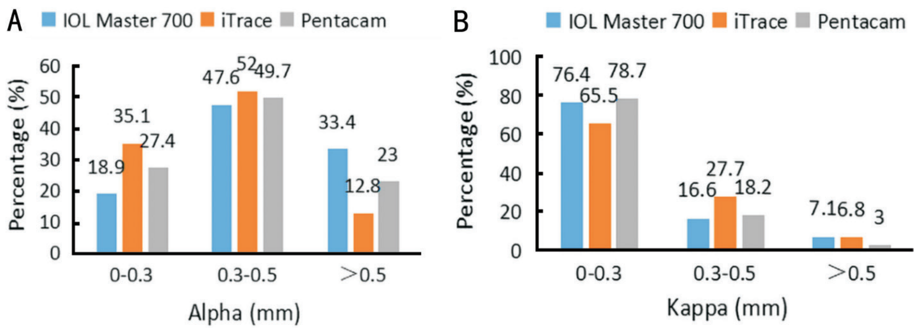

Figure 1 Histogram of the distribution of Alpha angle and Kappa angle measured by three instruments A: The distribution of Alpha angle measured by IOL Master 700, iTrace, and Pentacam; B: The distribution of Kappa angle measured by IOL Master 700, iTrace, and Pentacam.

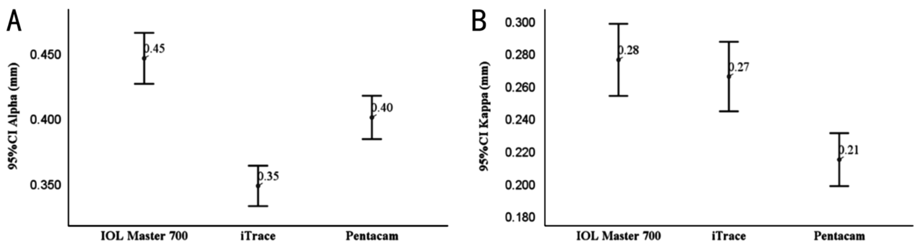

Figure 2 Box plots of Alpha angle and Kappa angle measured by three instruments A: The 95%CI of Alpha angle measured by IOL Master 700, iTrace and Pentacam; B: The 95% CI of Kappa angle measured by IOL Master 700, iTrace and Pentacam. 95%CI: 95% Confidence Interval.

0.025×K-0.058×WTW. Additionally, there was a linear correlation between the Kappa angle and age, K and WTW. The Kappa angle was modeled as Kappa=0.685+0.003×age-0.013×K-0.061×WTW (Table 2).

Distribution of Alpha and Kappa Angle in Cataract Patients Measured by Three Instruments The proportion of Alpha angle greater than 0.5 mm for the three instruments was 99 eyes (33.4%), 38 eyes (12.8%), and 68 eyes (23.0%), respectively. The proportion of Kappa angle greater than 0.5 mm for the three instruments was 21 eyes (7.1%), 20 eyes (6.8%), and 9 eyes (3.0%), respectively (Figure 1).

The Alpha angle measurements of IOL Master 700, iTrace and Pentacam were 0.45±0.17 mm, 0.35±0.14 mm, and 0.40±0.15 mm, respectively. The Kappa angle measurements of IOL Master 700, iTrace and Pentacam were 0.28±0.19 mm, 0.27±0.19 mm, and 0.21±0.14 mm, respectively (Figure 2).

Correlation of Alpha and Kappa Angle in Cataract Patients Measured by Three Instruments The scatter plots demonstrate a positive correlation between the measurements of the Alpha angle and Kappa angle obtained using the three instruments. Pearson analysis revealed a weak positive correlation between the sum of Alpha angle and Kappa angle obtained using the three instruments (r=0.291, P=0.000). The regression equation was y=0.33+0.26x. The IOL Master 700 showed a moderate positive correlation between the Alpha angle and Kappa angle (r=0.374, P=0.000) with the regression equation y=0.35+0.33x. The iTrace showed a weak positive correlation between the Alpha angle and Kappa angle (r=0.218, P=0.000) with the regression equation y=0.31+0.16x. The Pentacam also showed a weak positive correlation between the Alpha angle and Kappa angle (r=0.291, P=0.000) with the regression equation y=0.34+0.3x (Figure 3; Table 3).

Table 2 Multiple linear regression analysis of the effect of age, AL, ACD, K, WTW and LT on the Alpha and Kappa angle

Mode	B	β	t	P	F	Adjust R^2
Alpha						
Constant	2.230		5.292	0.000	13.955	0.149
Age	0.003	0.169	2.866	0.004		
AL	-0.036	-0.336	-4.742	0.000		
K	-0.025	-0.271	-4.108	0.000		
WTW	-0.058	-0.133	-4.634	0.023		
Kappa						
Constant	0.685		2.528	0.012	4.472	0.034
Age	0.003	0.139	2.408	0.017		
K	-0.013	-0.124	-2.138	0.033		
WTW	-0.061	-0.123	-1.991	0.047		

AL: Axial length; ACD: Anterior chamber depth; K: Keratometry; WTW: White to white distance; LT: Lens thickness; B: Regression coefficient; β: Standardized regression coefficient; R^2: Goodness of fit.

Consistency of Alpha and Kappa Angle in Cataract Patients Measured by Three Instruments For iTrace and IOL Master 700, iTrace and Pentacam, IOL Master 700 and Pentacam, the 95% limit of agreement of measured Alpha angles were -0.23 to 0.43 mm, -0.29 to 0.19 mm, and -0.26 to 0.35 mm, respectively. The 95% limit of agreement of measured Kappa angles were -0.43 to 0.45 mm, -0.29 to 0.39 mm, and -0.25 to 0.38 mm, respectively. There was no significant difference between only the Kappa angle measured by IOL Master 700 and iTrace (P=0.4254). A majority of measurements (96.28%) were inside the 95% confidence interval of the limit of agreement and evenly distributed near the mean difference line (Figure 4).

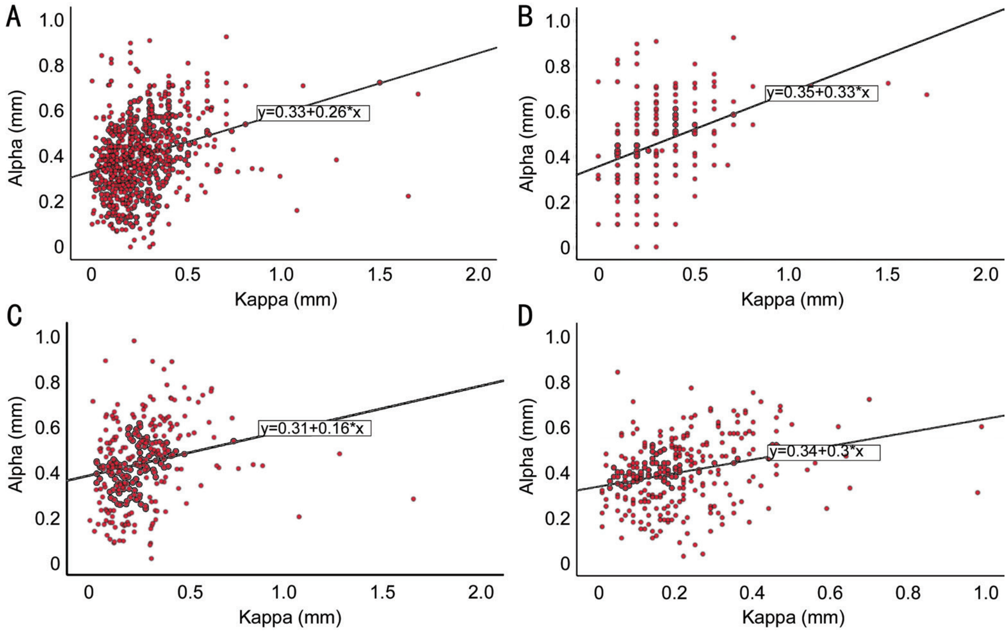

Figure 3 Scatter plots of Alpha angle and Kappa angle measured by three instruments A: The relation between total Alpha angle and total Kappa angle; B: The relation between Alpha angle and Kappa angle measured by IOL Master 700; C: The relation between Alpha angle and Kappa angle measured by iTrace; D: The relation between Alpha angle and Kappa angle measured by Pentacam.

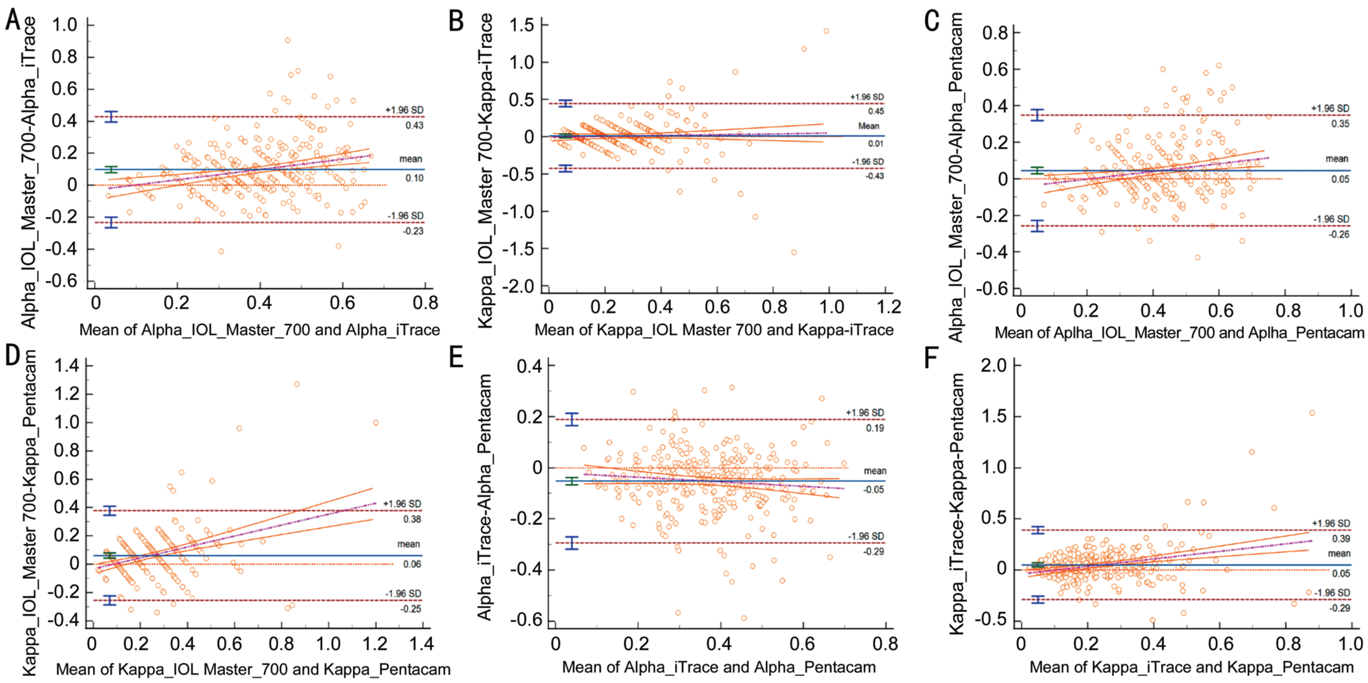

Figure 4 Bland-Altman plots of Alpha angle and Kappa angle measured in pairs among the three instruments A: The consistency of Alpha angle measured by IOL Master 700 and iTrace; B: The consistency of Kappa angle measured by IOL Master 700 and iTrace; C: The consistency of Alpha angle measured by IOL Master 700 and Pentacam; D: The consistency of Kappa angle measured by IOL Master 700 and Pentacam; E: The consistency of Alpha angle measured by iTrace and Pentacam; F: The consistency of Kappa angle measured by iTrace and Pentacam.

Variation Tendency of Preoperative and Postoperative Alpha and Kappa Angle Measured by Three Instruments The results of the paired *t*-test showed the paired differences between preoperative and postoperative Alpha angle and Kappa angle measured by IOL Master 700 were 0.00081 mm and 0.02958 mm, respectively, with no statistically significant differences (t=0.053, P=0.958, t=1.770, P=0.081). The paired differences between preoperative and postoperative Alpha angle and Kappa angle measured by iTrace were 0.026097 mm and 0.066472 mm, respectively, with statistical significance (t=2.614, P=0.011, t=2.722, P=0.008). The paired differences between preoperative and postoperative Alpha angle and Kappa angle measured by Pentacam were 0.02338 mm and 0.02559 mm, respectively, and the differences were statistically significant (t=2.393, P=0.018, t=2.123, P=0.036; Table 4).

Table 3 Pearson analysis of Alpha angle and Kappa angle measured by three instruments

Items	Alpha (mm)	Kappa (mm)
Total		
Alpha (mm)		
r	1	0.291[b]
P		0.000
n	888	888
Kappa (mm)		
r	0.291[b]	1
P	0.000	
n	888	888
IOL Master 700		
Alpha (mm)		
r	1	0.374[b]
P		0.000
n	296	296
Kappa (mm)		
r	0.374[b]	1
P	0.000	
n	296	296
iTrace		
Alpha (mm)		
r	1	0.218[b]
P		0.000
n	296	296
Kappa (mm)		
r	0.218[b]	1
P	0.000	
n	296	296
Pentacam		
Alpha (mm)		
r	1	0.291[b]
P		0.000
n	296	296
Kappa (mm)		
r	0.291[b]	1
P	0.000	
n	296	296

[b]$P<0.01$ (two-tailed), the correlation was statistically significant. *n*: Sample size; *r*: Correlation coefficient.

Effect of Age, AL, ACD, K, WTW and LT on Kappa Angle Changes The results of multiple linear regression analysis on the effect of age, AL, K, ACD, LT, and WTW on Kappa angle changes showed that there is a linear correlation between △Kappa and AL, K. △Kappa=1.136-0.021×AL-0.013×K (Table 5).

Impact of Preoperative Alpha and Kappa Angle Measured by iTrace on Postoperative Visual Quality The results of multiple linear regression analysis show that Alpha angle cannot predict HOA (β=-0.05, P=0.083), MTF (β=-0.045, P=0.162), PSF (β=0.023, P=0.398). Kappa significantly predicts HOA (β=0.18, P=0.000), MTF (β=0.171, P=0.000), PSF (β=0.088, P=0.000) positively (Table 6).

Table 4 Paired *t*-test of preoperative and postoperative Alpha angle and Kappa angle

Items	Mean±SD	PD	95%CI		*t*	*P*
			Lower	Lower		
IOL Master 700						
Alpha						
Preoperative	0.46±0.18	0.0008	0.0298	0.0314	0.053	0.958
Postoperative	0.46±0.17					
Kappa						
Preoperative	0.28±0.20	0.0296	0.0038	0.0629	1.770	0.081
Postoperative	0.25±0.14					
iTrace						
Alpha						
Preoperative	0.33±0.14	0.02610	0.0062	0.0460	2.614	0.011
Postoperative	0.30±0.13					
Kappa						
Preoperative	0.30±0.25	0.06647	0.0178	0.1152	2.722	0.008
Postoperative	0.23±0.24					
Pentacam						
Alpha						
Preoperative	0.39±0.14	0.0234	0.0041	0.0427	2.393	0.018
Postoperative	0.37±0.16					
Kappa						
Preoperative	0.23±0.16	0.0256	0.0018	0.0494	2.123	0.036
Postoperative	0.20±0.15					

CI: Confidence interval; PD: Paired differences; SD: Standard deviation.

Table 5 Multiple linear regression analysis of the effect of age, AL, ACD, K, WTW, and LT on Kappa angle changes

△ Kappa	*B*	β	*t*	*P*	*F*	Adjust R^2
Age (y)	-0.001	-0.093	-1.003	0.318	1.197	0.009
AL (mm)	-0.021	-0.288	-2.224	0.028		
K (D)	-0.013	-0.124	-2.138	0.033		
ACD (mm)	-0.012	-0.039	-0.407	0.685		
LT (mm)	-0.001	-0.005	-0.061	0.951		
WTW (mm)	0.019	0.052	0.548	0.585		

AL: Axial length; ACD: Anterior chamber depth; K: Keratometry; WTW: White to white distance; LT: Lens thickness; △Kappa: Kappa (preoperative)–Kappa (postoperative); *B*: Regression coefficient; β: Standardized regression coefficient; R^2: Goodness of fit.

Table 6 Multiple linear regression analysis of the impact of preoperative Alpha and Kappa angles on postoperative visual quality

Items	*B*	β	*t*	*P*	*F*	Adjust R^2
HOA						
Alpha (mm)	-0.05	-0.115	-1.743	0.083	24.718	0.204
Kappa (mm)	0.18	0.459	6.961	0.000		
MTF						
Alpha (mm)	-0.045	-0.095	-1.404	0.162	18.080	0.156
Kappa (mm)	0.171	0.405	5.965	0.000		
PSF						
Alpha (mm)	0.023	0.061	0.848	0.398	7.319	0.064
Kappa (mm)	0.088	0.259	3.617	0.000		

HOA: High-order aberrations; MTF: Modulation transfer function; PSF: Point spread function; *B*: Regression coefficient; β: Standardized regression coefficient; R^2: Goodness of fit.

DISCUSSION

The aim of this study is to compare the consistency and postoperative changes of preoperative Alpha angle and Kappa angle measured by commonly used precision biometric instruments (IOL Master 700, iTrace, and Pentacam) in clinical cataract surgery, as well as their impact on postoperative visual quality, in order to guide preoperative decision-making for MIOLs implantation.

The average AL of cataract patients in this study was 23.84±1.61 mm, ACD was 3.08±0.46 mm, K was 44.26±1.84 D, WTW was 11.70±0.39 mm, and LT was 4.05±0.97 mm, which is similar to the results reported by Jiang *et al*[21] and Wasser *et al*[22]. The former is measured using IOL Master 700, while the latter is measured using optical coherence tomography to obtain ocular biometric parameters of cataract patients. Research on healthy individuals across all age groups[23] indicates longer AL, deeper ACD, flatter K, shorter WTW, and thinner LT. This indicates that ocular biometric parameters change with age. The Alpha angle was modeled as Alpha=2.230+0.003×age-0.036×AL-0.025×K-0.058×WTW. The Kappa angle was modeled as Kappa=0.685+0.003×age-0.013×K-0.061×WTW. This suggests that Alpha angle is positively correlated with age and negatively correlated with AL, K, and WTW; Kappa angle is positively correlated with age and negatively correlated with K and WTW. Velasco-Barona *et al*[24] reported that Alpha angle was positively associated with age, K and negatively associated with AL in healthy people. Gharieb Ibrahim *et al*[25] found that Kappa angle was positively associated with age, and negatively associated with K, AL in healthy people. The discrepancy between our results and theirs may be related to the different study populations (cataract patients in our study versus healthy people in theirs) and is worth further investigation. The majority of the cataract population in this study were elderly people aged 50 and above. Compared with the healthy population of Gharib Ibrahim *et al*[25], age may affect this result. Additionally, the uneven opacity of the crystalline lens may cause a shift in the line of sight, resulting in difference of Kappa angle between the cataract population and the healthy population. These are possible reasons why our results differ from theirs. Meng *et al*[26], who also studied cataract patients, reported a similar finding to ours: older cataract patients with flatter K and shorter WTW are more likely to have larger Alpha angle and Kappa angle, but they further grouped them based on AL and concluded that Alpha angle decrease in eyes with AL less than 27.5 mm but increase in eyes with longer AL. In addition, their study also revealed a weak positive correlation between Alpha angle and Kappa angle. Our study further provides regression equation for the total Alpha angle and Kappa angle obtained by three instruments, which is y=0.33+0.26x. Furthermore, linear regression equations for the Alpha angle and Kappa angle of different instruments were provided. The regression equation for the Alpha angle and Kappa angle of IOL Master 700 is y=0.35+0.33x; The regression equation for the Alpha angle and Kappa angle of iTrace is y=0.31+0.16x; The regression equation for the Alpha angle and Kappa angle of Pentacam is y=0.34+0.3x. It can provide reference for doctors who are unable to obtain Alpha angle in clinical practice.

Comparison of consistency in measuring Alpha angle and Kappa angle pairwise using three different instruments, only the difference in Kappa angle measured by iTrace and IOL Master 700 was not statistically significant (P=0.4254). Bland-Altman plot revealed that good inter-instrument agreement between the IOL Master 700 and iTrace in terms of Kappa angle measurements and poor inter-instrument consistency for Alpha angle measurements, which is consistent with previous studies[27-28]. We found that the Alpha angle and Kappa angle measured by Pentacam are inconsistent with the other two instruments. This may be related to their different instrumental principles, the IOL Master 700 utilizes a slit-lamp photography technique to capture images of the eye, the iTrace utilizes the principle of placido rings, whereas the Pentacam utilizes Scheimpflug imaging. Kappa angle is the distance between the corneal reflection point (visual axis) and the center of the pupil (pupil axis), reflecting the degree to which the pupil axis deviates from the visual axis. Its size represents the neutrality of the pupil. The Kappa angle, as measured by the Pentacam, was the distance from the corneal curvature vertex to the center of the pupil, whereas the Kappa angle measured by the IOL Master 700 and iTrace was the distance from the corneal reflection point to the center of the pupil. This may be the reason why there is good consistency between only the IOL Master 700 and iTrace measurements of the Kappa angle. The ideal multi optical element optical system has overlapping optical axes, but due to the fact that the optical axes of the human cornea and the lens do not overlap or even are not parallel, the Alpha angle is further divided into the Alpha angle of the cornea and the Alpha angle of the lens. The Alpha angle of the cornea represents the neutrality of the cornea, while the Alpha angle of the lens represents the neutrality of the lens or intraocular lens. At present, all devices measure the Alpha angle of the cornea, which is the distance between the corneal center (corneal optical axis) and the corneal reflection point (visual axis), regardless of the centrality of the lens or intraocular lens. The three instruments define the corresponding point of the optical axis in the cornea as the center of the cornea, so the variation in corneal diameter will directly impact the measurement of the Alpha angle. The analysis of the influencing factors of Alpha angle in this study shows a negative correlation between Alpha angle and WTW, supporting this point. Differences in digital image processing algorithms and the inconsistent grayscale recognition of the angular scleral margin may result in discrepancies in the measurement of the corneal diameter. Therefore, the inconsistency in the Alpha angle measured by the three instruments may be attributed to the variations in digital image processing algorithms. In summary, there is currently no unified and accurate Alpha angle measuring instrument.

The proportion of Kappa angle measurements greater than 0.5 mm using the IOL Master 700, iTrace, and Pentacam were 21 eyes (7.1%), 20 eyes (6.8%), and 9 eyes (3.0%), respectively. Similarly, the proportion of Alpha angle measurements greater than 0.5mm using the IOL Master 700, iTrace, and Pentacam were 99 eyes (33.4%), 38 eyes (12.8%), and 68 eyes (23.0%), respectively. Fu *et al*[16] suggested to select patients for MIOLs implantation if they presented with an Alpha angle or Kappa angle smaller than 0.5 mm. This suggests that the majority of patients had a Kappa angle that was within the acceptable range for implantation of MIOLs, while a higher proportion of patients had an Alpha angle that was outside the acceptable range. In our study, Alpha angle and Kappa angle measured by iTrace and Pentacam 3mo after surgery were reduced, whereas the Alpha angle and Kappa angle measured by IOL Master 700 were no significant changes. The lack of significant change in the Alpha angle and Kappa angle measured by IOL Master 700 may be due to the fact that it calculates the Kappa angle and Alpha angle with only one digit retained for all measured values. Compared to the other two instruments that use a built-in method to directly obtain values that retain 2 to 3 decimal places, the changes are less significant. Although the exact cause of change in Kappa angle is unknown, factors that contribute to a shift in the line of sight or the pupillary axis could contribute to a change in Alpha angle and Kappa angle. The cataract lens is relatively large, and the IOL that replaces it is relatively thin, resulting in a decrease in the support force compared to pre-surgery. This can lead to changes in the position, shape, and size of the pupil. Studies have shown that there is a positive correlation between pupil center displacement and changes in pupil size. As the pupil diameter increases, the position of the pupil center also changes accordingly[29]. Additionally, the uneven opacity of the crystalline lens may also cause a shift in the line of sight, resulting in changes in the visual axis preoperatively and postoperatively[30]. In this study, multiple linear regression analysis was conducted by incorporating age, AL, K, ACD, LT, and WTW to further investigate the correlation between age, ocular biometric parameters, and the change of Kappa angle. The results showed that $\triangle$Kappa=1.136-0.021×AL-0.013×K. Using this standard equation before surgery can help clinicians predict this change and appropriately relax the standard for Kappa angle before MIOLs implantation. However, further studies are still needed, including extreme cases of AL and K, and larger sample sizes, to more accurately predict the change of Kappa angle.

In addition, the results of this study showed that Alpha angle cannot predict HOA (*P*=0.083), MTF (*P*=0.162), and PSF (*P*=0.398); Kappa angle significantly positively predicted HOA (*P*=0.000), MTF (*P*=0.000), and PSF (*P*=0.000). Therefore, Kappa angle measured by iTrace in this study can significantly positively predict postoperative visual quality indicators, while the Alpha angle does not affect postoperative visual quality. Compared with the previous study on the impact of Alpha angle on MIOLs, this study has the advantages of having a large sample size, and analyzing from multiple perspectives (such as poor consistency of multiple instrument measurements, measurement results of corneal Alpha angle being non true Alpha angle, and inability to predict postoperative visual quality), making the results more informative. In short, when selecting patients for MIOLs implantation, only consider the Kappa angle, without referring to the Alpha angle.

In summary, patients with older age, flatter K, and shorter WTW should be alert to the possibility of larger Alpha angle and Kappa angle, and Alpha angle should also consider the factor of AL. Kappa angle can significantly positively predict postoperative visual quality, while Alpha angle cannot. Therefore, when selecting patients for multifocal intraocular lens implantation, Kappa angle should be considered, and Alpha angle should not be considered. What's more, due to the significant decrease in Kappa angle at 3mo after surgery compared to before, the standard of preoperative Kappa angle <0.5 mm can be appropriately relaxed. The relaxed standard can be preliminarily predicted using $\triangle$Kappa=1.136-0.021×AL-0.013×K, but further research is needed.

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