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Interocular Agreement and Differences of Ocular Growth in Cataract Patients

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Abstract

Purpose: To investigate the interocular agreement and differences of ocular growth in cataract patients.

Methods: Ocular biometrics in both eyes of 715 cataract patients were measured by Lenstar LS-900 and retrospectively collected. We used axial length (AL) and axial length to corneal curvature ratio (AL/CR) as indicators of ocular growth. The patients were divided into 3 groups: group 1 (AL≤22mm in either eye), group 2 (22mm<AL<25mm in both eyes), and group 3 (AL≥25mm in either eye). The interocular agreement of AL and AL/CR was assessed by intraclass correlation coefficient (ICC), and the interocular differences were evaluated by Wilcoxon signed rank test and 95% limit of agreement (LoA). The correlations between interocular AL and AL/CR differences (ΔAL and ΔAL/CR) with interocular differences of other biometrics including central corneal thickness (ΔCCT), anterior chamber depth (ΔACD), lens thickness (ΔLT), lens position (ΔLP), flat corneal curvature (ΔK1), steep corneal curvature (ΔK2), anterior corneal astigmatism (ΔACA), white-to-white corneal diameter (ΔWTW), pupil size (ΔPS), and angle kappa (ΔAK) were evaluated by Spearman's correlation test and partial correlation test.

Results: The AL was significantly different between the right and left eyes in all subjects, females, and group 2 (all $P < 0.05$). The AL/CR ratio was not significantly different between the right and left eyes (all $P > 0.05$).

Higher interocular agreement of AL and AL/CR was observed in males (ICC = 0.948 and 0.959) than that in females (ICC = 0.872 and 0.910). Agreement of AL and AL/CR was higher in group 2 (ICC = 0.942 and 0.947) compared to that in group 1 (ICC = 0.166 and 0.782) and group 3 (ICC = 0.605 and 0.704). ΔAL was significantly correlated with ΔACD (r = 0.218), ΔLT (r = -0.103), ΔLP (r = 0.166), and ΔK1 (r = -0.112), and ΔAL/CR was significantly correlated with ΔACD (r = 0.097), ΔLP (r = 0.102), ΔK1 (r = -0.535) and ΔK2 (r = -0.481).

Conclusions: Interocular agreement of ocular growth varies in different sex and AL groups, and the interocular differences of ocular growth are associated with those of other ocular biometrics.

Keywords: Interocular Agreement; Ocular Growth; Ocular Biometrics; Cataract Surgery

Introduction

Cataract is the leading cause of visual impairment in aging adults globally. Patient with cataract are often accompanied by biometric changes in the eyes.[1] Among these ocular biometrics, axial length (AL), corneal curvature (CR), and axial length-to-corneal curvature ratio (AL/CR) are important parameters for understanding the patterns of ocular growth and optimizing intraocular lens (IOL) power calculations.[2,3] While interocular symmetry in biometric parameters is generally presumed in clinical practice, there are building evidences suggest that interocular asymmetry of some biometrics may also exist, which may potentially influence refractive accuracy and surgical outcomes.[4,5]

Previous studies about ocular biometrics have left gaps in understanding interocular agreement and differences of the ocular growth. For instance, sex-based variations of interocular symmetry in ocular anatomy and growth trajectories remain understudied. Similarly, patients with extreme AL range (long or short AL) may have distinct interocular dynamics compared to those with normal AL. Such differences could reflect different mechanisms of interocular symmetry.

This study aims to investigate interocular agreement and differences of AL and AL/CR in cataract patients, and analyze it in different sex and AL subgroups. By analyzing correlations between interocular biometric differences, we further explore how ocular growth disparities relate to other anatomical parameters. The findings may enhance preoperative assessments, improve IOL power calculations, and deepen the understanding of ocular development in cataract patients.

Methods

Participants: This study was conducted with adherence to the Declaration of Helsinki. The Institutional Review Board (IRB) of The People's Hospital of Baoan Shenzhen (BYL20240638) has approved the study, and waived the need for informed consent, because none of the patients' privacy was violated during the analysis of biometric data that had already existed.

This retrospective study included 715 cataract patients who underwent preoperative biometry in both eyes using the Lenstar LS-900 (Haag-Streit AG). Eligibility criteria included patients older than 45 years without history of ocular surgery, trauma, or corneal diseases. Exclusion criteria included poor fixation, unsatisfactory cooperation during examinations, dense cataract, advanced retinal or macular diseases, severe dry eye or corneal diseases, prior ocular surgery, trauma, or congenital anomalies.

Examinations

Lenstar LS-900 measurements were performed in both eyes at one sitting with short interval. We only included data without missing biometrics. Key parameters included AL, central corneal thickness (CCT), anterior chamber depth (ACD), lens thickness (LT), flat (K1) and steep (K2) corneal curvatures, anterior corneal astigmatism (ACA), white-to-white corneal diameter (WTW), pupil size (PS), and angle kappa (AK). AL/CR was calculated as AL divided by the mean corneal curvature (K1 + K2)/2. Lens position (LP) was calculated as ACD + 1/2 LT.[6,7]

We categorized the patients into three AL groups:

Group 1: AL ≤22 mm in either eye (n=45).

Group 2: 22 mm < AL <25 mm in both eyes (n=566).

Group 3: AL ≥25 mm in either eye (n=104).

Statistical analysis

We used Shapiro-Wilk tests to evaluate normality of the biometric data, and presented them as median (interquartile range). We assessed the interocular agreement by using intraclass correlation coefficients (ICC), and categorized it as "high" if ICC≥0.90, "moderate" if 0.75 ≤ ICC < 0.90, and "weak" if ICC < 0.75.[8] We evaluated the interocular differences with Wilcoxon signed-rank tests and 95% limits of agreement (LoA), and the 95% LoA interval which was calculated as the upper limit minus the lower limit.[9] Interocular biometric differences (Δ) were calculated as the right eye values minus the left eye values. We also used Spearman's correlation analyses to assess the relationships between ΔAL or ΔAL/CR and other interocular biometric differences (ΔCCT, ΔACD, etc.). Statistical significance was set at *P* <0.05.

Results

Sex and AL specific interocular comparisons of AL and AL/CR

Interocular comparisons of AL and AL/CR in different sex and AL subgroups are shown in Table 1. Significant interocular differences of AL were observed in all subjects (*P*=0.006), females (*P*=0.022), and Group 2 (*P*=0.008). Males and Groups 1 and 3 showed no significant differences in AL. No significant interocular differences of AL/CR were detected in any sex or AL subgroup (*P*>0.05).

Interocular agreement and differences of AL and AL/CR in different sex and AL subgroups

Interocular agreement and differences of AL and AL/CR in different sex and AL subgroups are shown in Table 2. Interocular agreement of AL was high in all subjects (ICC = 0.906, 95% LoA interval = 2.58mm), with higher agreement in males (ICC = 0.948, 95% LoA interval = 1.76mm) than that in females (ICC = 0.872, 95% LoA interval = 3.10mm). Interocular agreement of AL was high in Group 2 (ICC = 0.942, 95% LoA interval = 0.91mm), but was weak in Group 1 (ICC = 0.166, 95% LoA interval = 1.70mm) and Group 3 (ICC = 0.605, 95% LoA interval = 6.36mm).

Similarly, interocular agreement of AL/CR was high in all subject (ICC = 0.934, 95% LoA interval = 0.06mm), with slightly higher agreement in males (ICC = 0.959, 95% LoA interval = 0.04mm) than that in females (ICC = 0.910, 95% LoA interval = 0.08mm). Agreement of AL/CR was high in Group 2 (ICC = 0.947, 95% LoA interval = 0.04mm), and was weak in Group 1 (ICC = 0.782, 95% LoA interval = 0.05mm) and Group 3 (ICC = 0.704, 95% LoA interval = 0.14mm).

Correlations between biometric differences

Spearman's correlation coefficients of the correlations between interocular differences of AL and AL/CR with other biometric differences are shown in Table 3. ΔAL was positively correlated with ΔACD (*r* = 0.218, *P* < 0.0001) and ΔLP (*r* = 0.166, *P* < 0.0001), and negatively correlated with ΔLT (*r* = -0.103, *P* = 0.0058), and ΔK1 (*r* = -0.112, *P* = 0.0026). ΔAL/CR showed moderate negative correlations with ΔK1 (*r* = -0.535, *P* < 0.0001) and ΔK2 (r = -0.481, $P < 0.0001$), and a weak positive correlation with ΔACD (r = 0.097, P = 0.0095) and ΔLP (r = 0.102, P = 0.0063).

Discussion

In the present study we have found that sex and AL had an impact on the interocular agreement and differences of AL and AL/CR in cataract patients. Males and subjects with normal AL had higher agreement than those in females and subjects with short or long AL.

In this study, the interocular agreement and differences of AL varied across sex subgroups, consistent with previous studies that have found sex as one of the risk factors influencing interocular symmetry.[10,11] This sex-based disparity may reflect inherent anatomical or biomechanical differences, resulting in different ocular growth patterns between different genders.[12-15] Aligns with our data, previous studies have also reported sex disparities in AL distributions, with females generally having shorter AL than males.[16-18] Notably, the findings that females exhibit greater susceptibility to asymmetrical ocular elongation are possibly caused by hormonal factors or differences in scleral biomechanics. It was shown that asymmetry of scleral rigidity was present in patient with asymmetrical age-related macular degeneration.[19] Whether the higher degree of AL asymmetry in females are caused by more asymmetries in scleral biomechanics needs to be further studied. The smaller sex-related variation of interocular AL/CR agreement implies that corneal curvature may compensates for AL variations, thus maintaining proportional growth patterns.

Subgroup analysis also revealed distinct patterns in interocular agreement of AL and AL/CR in different AL subgroups. The highest agreement observed in group 2 (22 mm < AL <25 mm) suggests that biomechanical forces causing ocular elongation is well-balanced between the both eyes in this stage. In contrast, group 1 (AL≤22 mm) exhibited the lowest AL agreement (ICC=0.166), indicating asymmetry of ocular growth in patient of short eyes, but the AL/CR maintained moderate agreement (ICC=0.782), possibly due to the compensation of corneal curvature. Unsurprisingly, group 3 (AL≥25 mm) displayed the widest 95% LoA interval for AL (6.36 mm) and AL/CR (0.14). This finding underscores the structural instability and asymmetry in patients with highly elongated eyes, which may arise from asymmetrical scleral thinning or posterior segment distortions. Consistent with these findings of asymmetries, a previous study reported that binocular IOL power differences were more profound in patients with short or long eyes.[4] The lower interocular AL agreement in short eyes is also important in cataract surgery. It was shown that patients with short ALs had a wider variance in refractive outcome and a lower rate of achieving a postoperative refraction within ±0.50 D of the predicted target after immediately sequential bilateral cataract surgery.[20]

The strong overall interocular agreement of AL and AL/CR in all subjects supports the assumption of symmetry for these parameters in clinical practice. However, subgroup-specific variations of the interocular symmetry highlight the necessity for more detailed preoperative assessments, particularly in females and patients with short or long eyes, who may have more residual refractive error because of larger interocular biometric differences.[20,21] Future studies should explore longitudinal changes in these subgroups to elucidate causal mechanisms and refine surgical strategies.

ΔAL and ΔAL/CR were correlated with some interocular biometric differences. These relationships suggest that asymmetrical ocular growth is linked to anterior segment changes. For instance, larger ACD difference is associated with greater AL and AL/CR disparities. Similar interactions between interocular biometric differences has been reported.[22] Notably, the positive correlations between ΔAL and ΔAL/CR with ΔLP highlight the important role of ocular growth in modulating LP, which has clinical implications for refractive precision in cataract surgery. LP is a critical parameter in IOL calculation for cataract surgery. In group 1 and group 3, the larger interocular differences of AL and AL/CR are accompanied by larger LP differences, underscoring the importance of unilateral refractive planning for patients with short or long eyes. The correlations between ΔAL and ΔAL/CR with anterior segment parameters suggest that comprehensive biometric measurements, rather than AL only, should guide cataract surgical decision-making.

This study is limited by its retrospective design and lack of longitudinal data. Future research should explore causal mechanisms underlying sex and AL-based differences, as well as the impact of asymmetric ocular growth on refractive outcomes of cataract surgery. In addition, the potential confounding effect from factors such as genetics of ocular growth should also be addressed in future studies.

In conclusions, interocular agreement of ocular growth varies by sex and AL subgroups, with significant correlations between ΔAL and ΔAL/CR and other biometric differences. Our findings advocate for personalized biometric evaluations in cataract patients to optimize surgical outcomes.

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Legend Tables

Table 1: AL and AL/CR in the right and left eyes

	AL (mm)			AL/CR		
	ICC	OD minus OS*	95% LoA (interval)	ICC	OD minus OS*	95% LoA (interval)
All subjects	0.904	0.02 (0.24)	-1.28, 1.30 (2.58)	0.934	0.00 (0.01)	-0.03, 0.03 (0.06)
Males	0.948	0.02 (0.25)	-0.87, 0.89 (1.76)	0.959	0.00 (0.01)	-0.02, 0.02 (0.04)
Females	0.872	0.02 (0.24)	-1.54, 1.56 (3.10)	0.910	0.00 (0.01)	-0.04, 0.04 (0.08)
Group 1	0.166	0.02 (0.24)	-0.86, 0.84 (1.70)	0.782	0.00 (0.02)	-0.03, 0.02 (0.05)
Group 2	0.942	0.02 (0.21)	-0.44, 0.47 (0.91)	0.947	0.00 (0.00)	-0.02, 0.02 (0.04)
Group 3	0.605	0.03 (0.74)	-3.18, 3.18 (6.36)	0.704	0.00 (0.02)	-0.07, 0.07 (0.14)

*Presented as mean±standard deviation for normal distribution, and median (interquartile range) for skewed distribution; AL, axial length; AL/CR, axial length to corneal curvature ratio; [a] Wilcoxon signed rank test.

Table 2: Interocular agreement and differences of the AL and AL/CR

	AL (mm)			AL/CR		
	ICC	OD minus OS*	95% LoA (interval)	ICC	OD minus OS*	95% LoA (interval)
All subjects	0.904	0.02 (0.24)	-1.28, 1.30 (2.58)	0.934	0.00 (0.01)	-0.03, 0.03 (0.06)
Males	0.948	0.02 (0.25)	-0.87, 0.89 (1.76)	0.959	0.00 (0.01)	-0.02, 0.02 (0.04)
Females	0.872	0.02 (0.24)	-1.54, 1.56 (3.10)	0.910	0.00 (0.01)	-0.04, 0.04 (0.08)
Group 1	0.166	0.02 (0.24)	-0.86, 0.84 (1.70)	0.782	0.00 (0.02)	-0.03, 0.02 (0.05)
Group 2	0.942	0.02 (0.21)	-0.44, 0.47 (0.91)	0.947	0.00 (0.00)	-0.02, 0.02 (0.04)
Group 3	0.605	0.03 (0.74)	-3.18, 3.18 (6.36)	0.704	0.00 (0.02)	-0.07, 0.07 (0.14)

Correlations of interocular biometric differences with AL and AL/CR.*

*Presented as median (interquartile range); AL, axial length; AL/CR, axial length to corneal curvature ratio; ICC, intraclass correlation coefficient; LoA, limit of agreement.

Table 3: Correlations of interocular biometric differences with AL and AL/CR.*

Interocular difference	ΔAL	P	ΔAL/CR	P
ΔCCT	0.065	0.084	-0.029	0.445
ΔACD	**0.218**	**<0.0001**	**0.097**	**0.0095**
ΔLT	**-0.103**	**0.0058**	-0.015	0.692
ΔLP	**0.166**	**<0.0001**	**0.102**	**0.0063**
ΔCCR	**-0.177**	**<0.0001**	-0.054	0.150
ΔK1	**-0.112**	**0.0026**	**-0.535**	**<0.0001**
ΔK2	-0.073	0.050	**-0.481**	**<0.0001**
ΔACA	0.003	0.929	0.047	0.205
ΔWTW	0.022	0.552	0.029	0.443
ΔPS	0.024	0.515	0.011	0.768
ΔAK	-0.005	0.892	0.046	0.221

*Presented as Spearman's correlation coefficients and bold number indicates P<0.05; AL, axial length; AL/CR, axial length to corneal curvature ratio; CCT, central corneal thickness; ACD, anterior chamber depth; LT, lens thickness; LP, lens position; CCR, chamber crowd ratio; K1, flat corneal curvature; K2, steep corneal curvature; ACA, anterior corneal astigmatism; WTW, white-to-white corneal diameter; PS, pupil size; AK, angle kappa.

Table 4: Correlations of interocular biometrics differences with intraocular lens power difference

	Univariate regression		Multivariate regression	
	beta	95% CI	beta	95% CI
ΔCCT (μm)	**-1.22**	**-1.82 to -0.62**	0.00	0.00 to 0.00
ΔACD (mm)	**-0.02**	**-0.03 to -0.01**	-0.01	-0.07 to 0.05
ΔLT (mm)	0.01	0.00 to 0.02		
ΔAL (mm)	**-0.35**	**-0.35 to -0.34**	**-2.61**	**-2.63 to -2.59**
ΔK1 (diopter)	**-0.07**	**-0.10 to -0.04**	**-0.45**	**-0.47 to -0.43**
ΔK2 (diopter)	**-0.11**	**-0.14 to -0.09**	**-0.46**	**-0.48 to -0.44**
ΔACA (diopter)	**-0.04**	**-0.07 to -0.004**	VIF>10	
ΔWTW (mm)	-0.01	-0.03 to 0.00		
ΔPS (mm)	0.01	-0.02 to 0.04		
ΔAK (mm)	0.00	-0.01 to 0.01		

CI, confidence interval; CCT, central corneal thickness; ACD, anterior chamber depth; LT, lens thickness; AL, axial length; K1, flat corneal curvature; K2, steep corneal curvature; ACA, anterior corneal astigmatism; WTW, white-to-white corneal diameter; PS, pupil size; AK, angle kappa; bold numbers indicate P<0.05.