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Relationship between angle kappa, angle alpha and objective visual quality in patients with multifocal intraocular lens

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植入多焦点人工晶状体患者 κ 角和 α 角与视觉质量的关系

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摘要

目的:探讨 κ 角和 α 角对多焦点人工晶状体(mIOLs)植入后患者视觉质量的影响。

方法:回顾性队列研究。纳入接受超声乳化白内障吸除联合 mIOLs 植入术的患者 46 例 46 眼。使用 iTrace 测量术前 κ 角、α 角,术后波前像差,分别分析其与角膜、眼内及全眼视觉质量之间的相关性。

结果:在 3 mm 瞳孔大小时,κ 角的大小与眼内和全眼调制传递函数(MTF)呈负相关;κ 角的大小与3 mm瞳孔时眼内和全眼的散光、三叶、高阶像差(HOAs)呈正相关。在 3 mm瞳孔时,α 角的大小与全眼 MTF 和全眼 Strehl 比呈负相关。α 角的大小与 5 mm 瞳孔时的角膜彗差、3 mm 和 5 mm 瞳孔时的眼内散光以及 3 mm 瞳孔时的全眼球差(SA)呈正相关。多元线性回归分析显示,在候选自变量(κ 角、α 角、散光、SA、彗差、三叶草和 HOAs)中,散光是改变 3 mm 和 5 mm 瞳孔时角膜 MTF 的唯一独立因素;散光和 HOA 成为改变 3 mm 和 5 mm 瞳孔时眼内 MTF 以及 3 mm 瞳孔时全眼 MTF 的独立因素;散光、SA 和 HOAs 成为改变 5mm 瞳孔时全眼 MTF 的独立因素。

结论:随着术前 κ 角或 α 角的增大,接受 mIOL 植入的患者往往会出现较大的眼内散光和 HOA,导致视觉质量差,尤其是瞳孔较小的患者。

关键词:κ 角;α 角;调制传递函数;白内障;斯特列尔比

Abstract

• AIM: To investigate how angles kappa and alpha affect postoperative visual quality in patients with multifocal intraocular lens (mIOLs) implantation.

• METHODS: Retrospective cases series. A total of 46 patients (46 eyes) who underwent phacoemulsification were subsumed. The correlation between Preoperative angles kappa and alpha, wave - front aberrations and objective visual quality of cornea, internal, and total eye after surgery were analyzed using iTrace.

• RESULTS: The magnitude of angle kappa was negatively correlated with internal and total modulation transfer function (MTF) at 3 mm; the magnitude of angle kappa was positively correlated with astigmatism, trefoil, higher- order aberrations (HOAs) of both internal and total eye at 3 mm. The magnitude of angle alpha was negatively correlated with total MTF and total Strehl ratio at 3 mm. The magnitude of angle alpha was positively correlated with corneal coma at 5 mm, internal astigmatism at both 3 mm and 5 mm, and total spherical aberration (SA) at 3 mm. Multivariate linear regression analysis showed that, among candidate independent variables (kappa, alpha, astigmatism, SA, coma, trefoil, and HOAs), astigmatism is the only independent factor for altering corneal MTF at 3 mm and 5 mm; astigmatism and HOAs emerged as independent factors for altering internal MTF at 3 mm and 5 mm, and total MTF at 3 mm; astigmatism, SA and HOAs emerged as independent factors for altering total MTF at 5 mm.

• CONCLUSION: With greater preoperative angle kappa or angle alpha, patients who accept mIOL implantation tend to have larger internal astigmatism and HOAs, which resulting in poor visual quality, especially those with small pupil size.

• KEYWORDS: angle kappa; angle alpha; modulation transfer function; cataract; Strehl ratio
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INTRODUCTION

Cataract is now the principal consideration of preventable blindness on earth[1-2]. With the rapid increasing in quantity of cataract surgeries, patient demands are becoming the main challenge for cataract surgeons. More and more patients are expecting an excellent postoperative visual acuity at all distance without complications or visual compromises. Multifocal intraocular lens (mIOLs) is developed to provide cataract patients with a clear vision and satisfied visual acuity at different focal points without additional spectacle correction[3].Despite high levels of overall patients' satisfaction after mIOLs implantation during cataract surgery, most of them complained about photic phenomena such as glare, halos, and dysphotopsia even with excellent uncorrected visual acuity (UCVA)[4]. According to previous research, these postoperative photic phenomena are thought to be associated with intraocular lens (IOL) decentration, retained lens fragments, posterior capsular opacity, dry-eye syndrome, uncorrected spectacles dependence, residual astigmatism, and postoperative spherical equivalent[5-7]. Even though some issues of these questions can be further resolved through surgery, it remains significantly indispensable to choose ideal cases during the preoperative exams to satisfied both patients and operators with optimal postoperative outcomes. Some recent researches have been focusing on the optical biometry of patients before mIOLs implantation and intended to find patient selection criteria[7-8]. The latest studies covered that angle kappa, the angular distance between the visual axis and the pupillary axis, may be responsible for postoperative photic phenomena. A large angle kappa might cause postoperative photic phenomena such as glare and halos in patients with mIOLs implantation, nevertheless, there are also many patients with a large angle kappa values who have no symptoms[7]. Similar to angle kappa, angle alpha, defined as the intersection of the visual axis and the optic axis, was thought to be related to the postoperative visual quality as well[9-11].

In our previous study, significant difference was found between preoperative and postoperative angle kappa, while angle alpha was thought to be more reliable and stable than angle kappa[12]. However, it is still unclear that how those two factors affect the surgical outcome. With different designed premium IOL been implanted, does large angles kappa and alpha always affect visual outcome. This research is aiming at detecting the relationship among angle kappa, angle alpha, ocular aberrations and objective visual quality in patients with multifocal diffractive IOL implantation.

SUBJECTS AND METHODS

Ethical Approval Patients who planned to undergo cataract surgery at the First Affiliated Hospital of Northwest University were included. Each eye was considered as a single case and all examinations in the study were done monocularly. All candidates underwent phacoemulsification surgery with the implantation of two different designed diffractive bifocal IOLs. This study was performed in accordance with the tenets of the Declaration of Helsinki and has been approved by the local ethics committee of the First Affiliated Hospital of Northwest University (No.2019-08). All patients had signed the written informed consent.

Inclusion criteria were as follows: 1) lens opacity grading greater than C1N1P0 according to Lens Opacities Classification System III[13]; 2) corneal astigmatism less than 0.75 diopters. Exclusion criteria for the study included a history of any other ocular pathology, previous ocular surgery, posterior capsular opacification, patients without the implantation of mIOL because of unrealistic expectations.

Preoperative and Postoperative Assessment Preoperative assessment was performed within 2 days before surgery, and postoperative assessment was performed at 3 months follow-up visit. A full ophthalmological examination was taken for all candidates, which included slit lamp biomicroscopy examination for both anterior and posterior segments of the eye, uncorrected distance visual acuities (UDVA), uncorrected near visual acuities (UNVA), corrected distance visual acuities (CDVA), intraocular pressure (IOP) with non-contact tonometer (CT-80A, Topcon, Japan), optical coherence tomography (OCT, Heidelberg engineering), and optical biometry (Len-star LS 900, HAAG-STREIT). Wave-front aberrations, the same as optical visual quality were determined by iTrace (Tracey Technologies, Houston, TX, USA), which will be described in detail in the following part.

Intraocular Lens Selection The abilities of correcting spherical aberration of ZMB00 (Johnson & Johnson Vision, USA) and 809MP (Carl Zeiss Meditec SAS, France) was different. The spherical aberration of ZMB00 and 809MP are −0.27 μm and −0.18 μm, respectively. During preoperative examination, the corneal spherical aberration at 6 mm of patients were measured by iTrace, and the model of IOLs was decided with the goal to remove as much of corneal spherical aberration as was possible.

Surgical technique All surgeries were performed by the same surgeon under topical anesthesia (Benoxil 0.4% solution, 3 times, Santen) using a standard technique of phacoemulsification. A 2.4 mm clear corneal incision was made with a diamond knife at the steep axis to loosen the corneal astigmatism. An auxiliary incision was made about 90 degrees clockwise angle from the main incision. A central continuous circular capsulorhexis was performed, followed by hydrodissection and phacoemulsification cataract extraction. All IOLs were implanted into the capsular bag. Tobramycin/

dexamethasone (0.3%/0.1%, Alcon) and antibiotic eyedrops (Cravit 0.5%, Santen) were used 4 times per day for 2 wk, and non-steroidal anti-inflammatory drugs (Bronuck, Senju) and artificial tears (Hycosan, 0.1%, Eusan) were used 2 times per day for 4 wk by all patients postoperatively. All surgeries went well and ended successfully, and there were no intraoperative or postoperative complications.

Optical biometric parameter iTrace aberrometer was manipulated by a sophisticated technician to exam all patients' optical biometric parameter pre - and postoperatively, including angle kappa and angle alpha, keratometry, wave-front aberrations, Strehl ratio, and modulation transfer function (MTF). The patient was asked to fixate on the red light under scotopic condition for the first examination. The limbus and the pupil were detected automatically by the instrument's software, resulting in the white-to-white measurement and pupil diameter. The centers of the cornea and pupil were also located automatically, and the distance and orientation relative to the visual axis were calculated. After that, patients' pupil was dilated to more than 6 mm for the second check. Corneal topography and wave-front were measured to calculate total eye and internal eye aberrations and be presented by Root-mean-square (RMS) terms. A point-to-point optical ray-tracing technology was used to detect the retinal image of a point-like object, and acquired the Strehl ratio of the eye. The MTF curves due to high order aberrations were evaluated. Three measurements of each eye were captured, and the best scan (the image with the best quality peaks for individual points) was chosen for the final analysis. These parameters were recorded separately from cornea, internal eye and total eye.

Statistical Analysis Statistical testing was performed with SPSS Windows software (version 17.0, SPSS, Inc.). The variables were calculated and documented as the mean ± standard deviation (SD). Population analysis was described with mean values. Paired t-tests were performed to test for significant differences in the visual acuity, IOP, and other optical biometric parameters preoperatively and postoperatively. Pearson correlation analysis was performed for correlation analysis among angle kappa, angle alpha, wave-front aberrations, and objective visual quality. A multivariate linear regression analysis was performed to verify variables that independently influenced MTF of cornea, internal, and total eye.

RESULTS

A total of 46 eyes (22 cases of left eye and 24 cases of right eyes) from 46 candidates underwent phacoemulsification, and finished the follow-up examination postoperatively. The mean age was 66.06±9.55 (37 to 83) years. There were 21 male (46%) and 25 female (53%). ZMB00 and 809MP were implanted in 21 (46%) and 25 (54%) eyes, respectively. There was a significant difference between preoperative UDVA and postoperative UDVA (LogMAR 0.76±0.45 *vs* 0.10±0.75, P=0.000). Preoperative CDVA (LogMAR) was 0.46±0.45, which was significantly lower than postoperative CDVA (LogMAR 0.04±0.06, P=0.005). Postoperative UNVA (LogMAR) was 0.20±0.20. Postoperative IOP was trending lower than preoperative IOP (16.17±2.09 *vs* 15.30±1.97 mmHg, P=0.058). The ocular general biometric data was stated in Table 1.

Objective visual quality The average height of MTF curves due to higher-order aberrations (HOAs) and Strehl ratio of cornea, internal and total eye at 3 mm and 5 mm were shown in Table 2. Both corneal MTF (r=0.344, P=0.022) and internal MTF (r=0.550, P=0.000) were positively correlated with total MTF at 3 mm. At 5 mm scanning zone, internal MTF was positively correlated with total MTF (r=0.477, P=0.006). Corneal Strehl ratio was positively correlated with total Strehl ratio (r=0.308, P=0.042) at 3 mm. Both corneal Strehl ratio (r=0.352, P=0.048) and internal Strehl ratio (r=0.531, P=0.002) were positively correlated with total Strehl ratio at 5 mm. No correlationship was found between corneal and internal MTF (r=−0.042, P=0.785 at 3 mm, r=−0.012, P=0.946 at 5 mm), and between corneal and internal Strehl ratio (r=−0.007, P=0.966 at 3 mm, r=0.048, P=0.793 at 5 mm).

The correlations between MTF and angle kappa, MTF and angle alpha, wave-front aberrations and angle kappa, wave-front aberrations and angle alpha were calculated for cornea, internal, and total eye at 3 mm and 5 mm scanning zone (Figure 1). The magnitude of preoperative angle kappa (0.24±0.20 mm) was negatively correlated with internal MTF (r=−0.365, P=0.016) and total MTF (r=−0.375, P=0.013) at 3 mm scanning zone (Figure 2A). The magnitude of preoperative angle alpha (0.29±0.14 mm) was negatively correlated with total MTF (r=−0.325, P=0.003) and total Strehl ratio (r=−0.306, P=0.046) at 3 mm scanning (Figure 2C and 2D). The magnitude of preoperative angle kappa (0.24±0.20 mm) was positively correlated with internal astigmatism (r=0.325, P=0.003, Figure 3A), internal trefoil (r=0.435, P=0.004), internal HOAs (r=0.520, P=0.000, Figure 3C), total astigmatism (r=0.468, P=0.002), total trefoil (r=0.350, P=0.021), and total HOAs (r=0.530, P=0.000) at 3 mm scanning zone. The magnitude of preoperative angle alpha (0.29±0.14 mm) was positively correlated with corneal coma (r=0.375, P=0.034) at 5 mm, internal astigmatism (r=0.360, P=0.018) at both 3 mm and 5 mm (Figure 3E and 3F), and total spherical aberration (r=0.323, P=0.035) at 3 mm scanning zone.

Table 1 Optic biometric parameters of the participants

($\bar{x}\pm s$, mm)

Parameters	Preoperative (n=46)
Axial length	23.92±1.80 (21.06, 27.02)
White to white	11.55±0.60 (10.45, 12.33)
Lens thickness	4.31±0.52 (3.15, 5.18)
Anterior chamber depth	3.21±0.53 (2.14, 4.41)
The magnitude of Kappa	0.25±0.20 (0.02, 0.98)
The magnitude of Alpha	0.29±0.14 (0.01, 0.73)

Table 2　Correlation analysis of modulation transfer function and Strehl ratio among cornea, internal, and total eye

Items			Total eye	r	P
MTF					
3 mm	Cornea	0.42±0.12	0.36±0.12	0.344	0.022[a]
	Internal	0.43±0.12		0.550	0.000[a]
5 mm	Cornea	0.31±0.07	0.28±0.07	0.165	0.366
	Internal	0.31±0.07		0.477	0.006[a]
Strehl ratio					
3 mm	Cornea	0.18±0.13	0.15±0.14	0.308	0.042[a]
	Internal	0.22±0.17		0.227	0.138
5 mm	Cornea	0.05±0.02	0.04±0.02	0.352	0.048[a]
	Internal	0.05±0.02		0.531	0.002[a]

[a]$P<0.05$. MTF: Modulation transfer function.

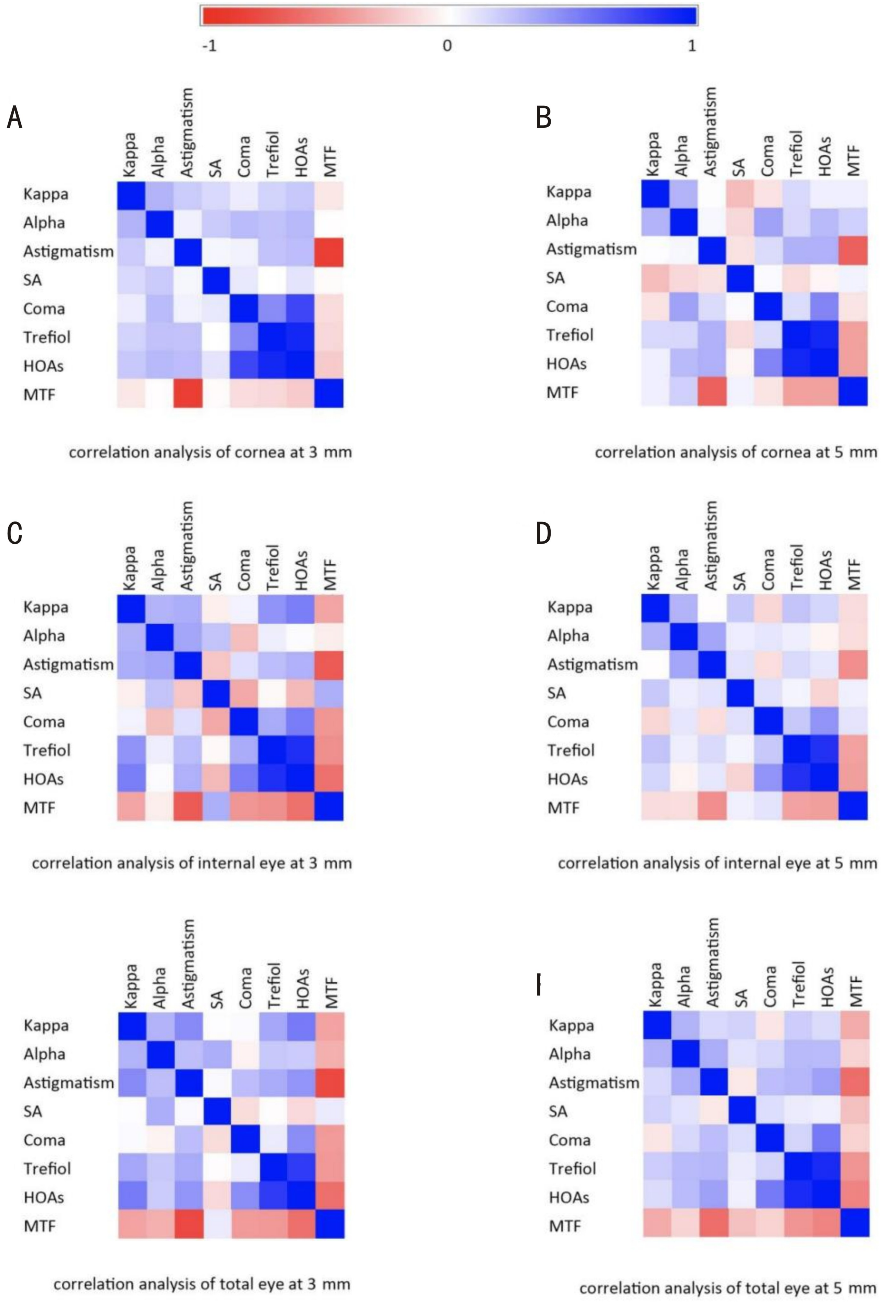

Figure 1　Correlation matrix among angel kappa, angle alpha, modulation transfer function, and wave-front aberrations of the cornea, internal, and total eye at 3 mm and 5 mm scanning zone. Red indicates a negative correlation and blue indicates a positive correlation.　A and B: Correlation matrix of the cornea at both 3 mm (A) and 5 mm (B); C and D: Correlation matrix of the internal eye at both 3 mm (C) and 5 mm (D); E and F: Correlation matrix of total eye at both 3 mm (E) and 5 mm (F). SA: Spherical aberration; HOAs: High-order aberrations; MTF: Modulation transfer function.

To identify variables that independently influenced changes in MTF, a multivariate linear regression analysis was performed. Candidate independent variables were angle kappa, angle alpha, low-order aberration with no defocus (astigmatism), spherical aberration, coma, trefoil, and HOAs. The regression analysis was performed with corneal MTF, internal MTF, and total MTF to be the dependent variables at 3 mm and 5 mm scanning zone, respectively. Consequently, astigmatism is the only independent factors for altering corneal MTF at 3 mm and 5 mm; astigmatism and HOAs emerged as independent factors for altering internal and total MTF at 3 mm, and internal MTF at 5 mm; astigmatism, spherical aberration and HOAs emerged as independent factors for altering total MTF at 5 mm. The results are shown in Table 3.

DISCUSSION

Angle kappa is the intersection of the visual axis and the pupillary axis[14]. Angle alpha is the intersection of the visual axis and the optic axis and was first measured by Tscherning using an ophthalmophakometer[15]. In former studies, angle kappa has been found to be related with the visual quality after mIOLs implantation, when angle kappa was greater than 0.5 mm, patients' visual quality decreased and when angle kappa was greater than 0.4 mm, the incidence of glare and halo increased[16]. However, Angle kappa may change after phacoemulsification[12]. The association between angle kappa and discontented photic phenomena is still unknown. Several scholars put forward a theory that similar to the IOL decentration, a greater angle kappa would lead a fovea centric ray passing closer to the edge of the IOL ring instead of the center of the IOL[7]. In this study, the magnitude of preoperative angle kappa was found to be positively correlated to astigmatism, trefoil and HOAs of both internal and total eye at 3 mm scanning zone under photopic condition. These findings proved that the larger angle kappa was, the more internal aberrations there would be, especially in patients with small pupil size. Similar to angle kappa, the magnitude of angle alpha was found to be positively correlated with internal astigmatism at both 3 mm and 5 mm. Besides, angle alpha was

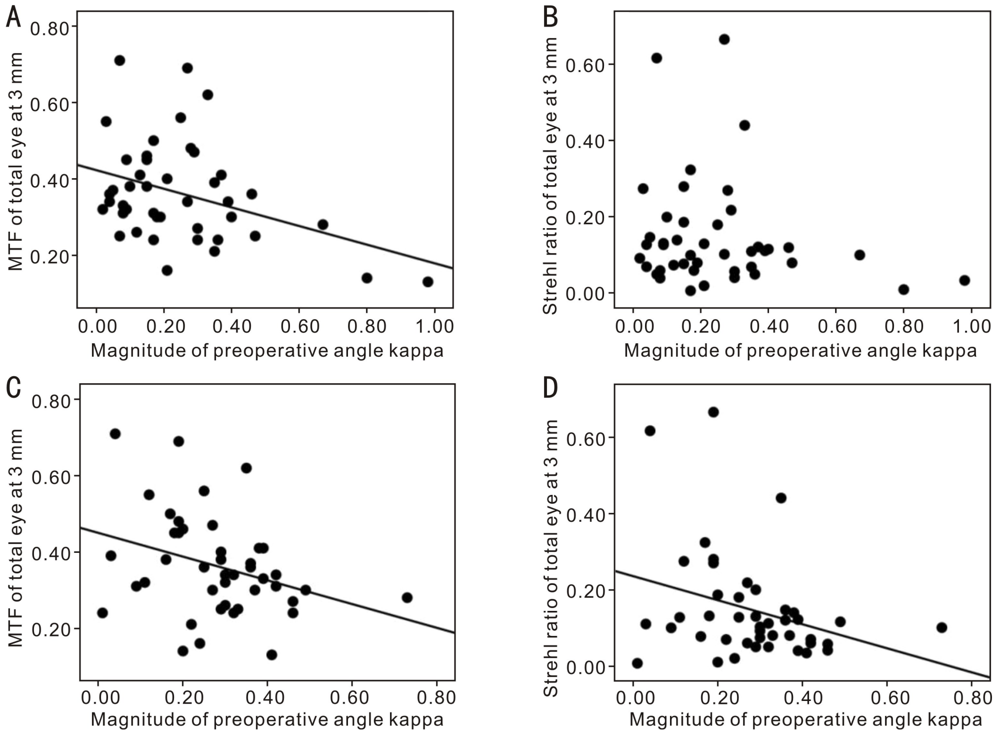

Figure 2 Scatter plot of angle kappa, angle alpha, and objective visual quality at 3 mm scanning zone. A: The magnitude of preoperative angle kappa was negatively correlated with the MTF of the total eye; B: There was no significant correlation between the magnitude of preoperative angle kappa and the Strehl ratio of the total eye; C and D: The magnitude of preoperative angle alpha was negatively correlated with MTF and Strehl ratio of the total eye. MTF: Modulation transfer function.

Table 3 Multivariate linear regression analysis

Dependent variables	Independent variables	3 mm		5 mm	
		Standardized β	*P* (95% *CI*)	Standardized β	*P* (95% *CI*)
MTF (cornea)	astigmatism	−0.852	0.000 (−1.240, −0.832)	−0.664	0.000 (−0.265, −0.108)
MTF (internal)	astigmatism	−0.562	0.000 (−1.230, −0.583)	−0.427	0.009 (−0.332, −0.052)
	HOAs	−0.424	0.000 (−1.049, −0.375)	−0.354	0.027 (−0.418, −0.027)
MTF (total)	astigmatism	−0.674	0.000 (−0.803, −0.461)	−0.516	0.001 (−0.182, −0.052)
	HOAs	−0.315	0.001 (−0.861, −0.231)	−0.296	0.044 (−0.208, −0.003)
	spherical	-	-	−0.279	0.041 (−0.686, −0.015)

MTF: Modulation transfer function; HOAs: Higher-order aberrations.

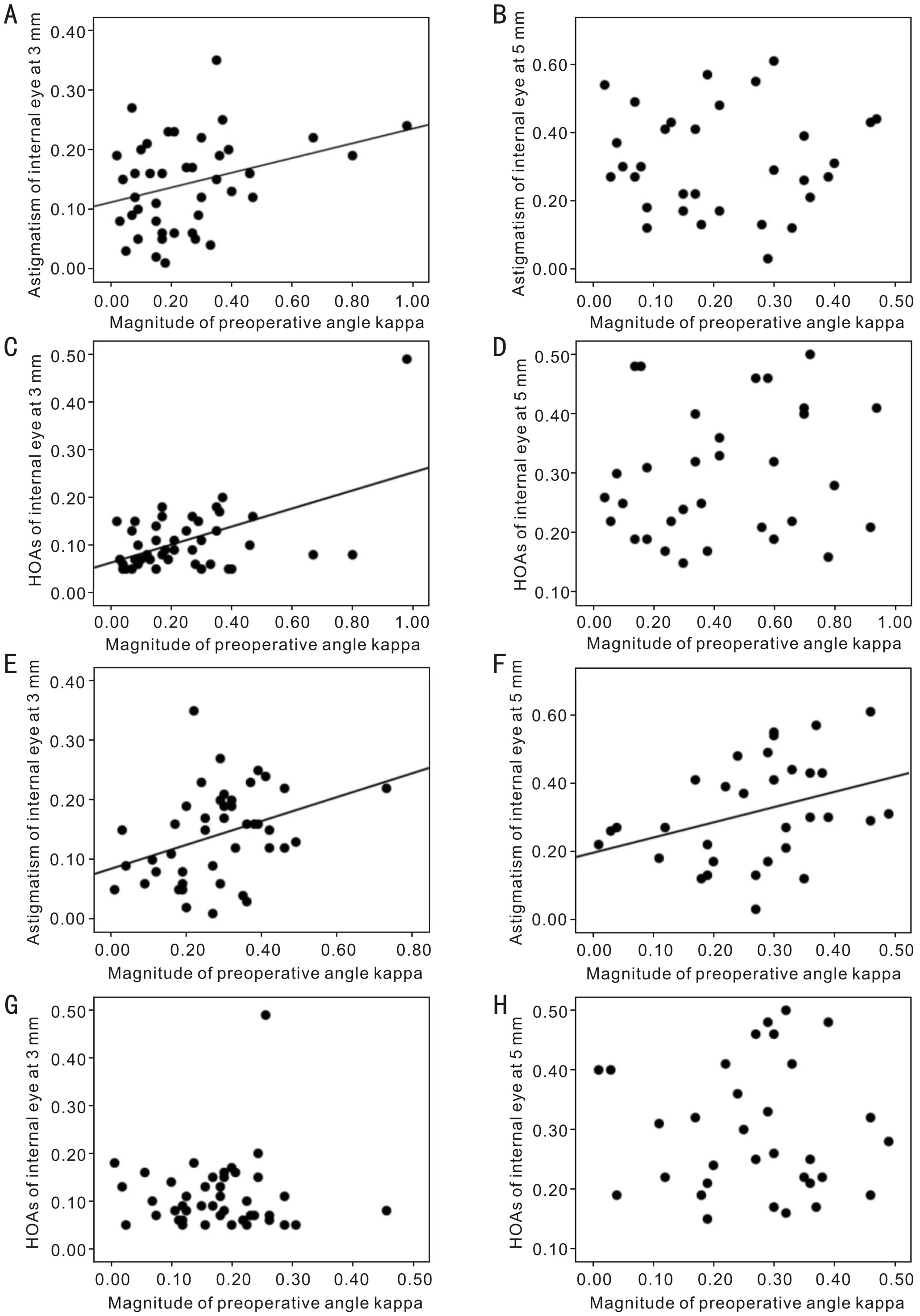

Figure 3　Scatter plot of angle kappa, angle alpha, and internal aberrations at both 3 mm and 5 mm scanning zone.　A to D: The magnitude of preoperative angle kappa was positively correlated with astigmatism (A) and HOAs (C) of the internal eye at 3 mm, no correlation was found between those parameters at 5 mm (B and D). E to H: The magnitude of preoperative angle alpha was positively correlated with internal astigmatism at both 3 mm and 5 mm (E and F); however, no correlation was found between the magnitude of preoperative angle alpha and HOAs at 3 mm and 5 mm (G and H). HOAs: Higher-order aberrations.

positively correlated with corneal coma at 5 mm, which was understandable, because according to the definition of angle alpha, the greater of angle alpha, the larger of the distance from visual axis to corneal center.

Do larger angles kappa and alpha directly cause poor visual quality. Both MTF and Strehl ratio theoretically reflect optical visual quality. MTF describes the relationship between the contrast of the visible image and imaging quality of the optical system at different frequencies, and expresses the symmetrical aberration. The greater the MTF value is, the clearer the image is[17]. Strehl ratio is an important objective index to evaluate the quality of retinal imaging. It is defined as the ratio of peak focal intensities in the aberrated and ideal optical point spread function[18]. In this study, the magnitude of preoperative angle kappa was negatively correlated with internal MTF and total MTF at 3 mm scanning zone under photopic condition, and the magnitude of angle alpha was negatively correlated with total MTF and total Strehl ratio at 3 mm. however, multivariate linear regression analysis showed that astigmatism and HOAs emerged as independent factors for altering total MTF at 3 mm; astigmatism, spherical aberration and HOAs emerged as independent factors for altering total MTF at 5 mm. These finding could explain why there were still a lot of candidates with high angle kappa values have no symptoms. It also suggests that angles kappa and alpha maybe affect postoperative visual quality by inducing internal astigmatism or HOAs.

Ideally, the center of mIOLs should be concentric with optic refractive system to make a clear image on the retina. However, in patient with large angles kappa and alpha, it is hard to guarantee the position of an IOL is functionally well-centered. Further researches should be done to look into the detail of how angles kappa and alpha associated with internal aberrations, and find ways to make IOL match angles kappa and alpha individually. Donnenfield and Holladay have performed argon laser iridoplasties to centre the pupil and eliminate waxy vision in patients with high angle kappa[19]. Before we could find an effective method to solve this problem, surgeons should pay more attention in cataract patients with large angles kappa and alpha, especially those with small pupil size.

In summary, in cataract patients with greater preoperative angle kappa or angle alpha which induce more internal eye aberrations are more likely to experience photic phenomena and result in unsatisfactory visual quality after mIOLs implantation.

Conflicts of Interests: Zhu CJ, None; Long T, None; Ma T, None; Yan J, None; Wang R, None.

Authors' contributions: Zhu CJ designed project, implemented research, organized and analyzed data, and wrote the paper; Long T: designed the project, implemented research, and measured the data; Ma T conducted research measure and organized data, and provided research guidance; Yan J organized the data and revised paper; Wang R: designed the project, conducted statistical analysis, revised paper, and provided fund support.

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