ORIGINAL RESEARCH

Distribution and related factors of corneal regularity and posterior corneal astigmatism in cataract patients

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Purpose: To study the distribution of posterior corneal astigmatism (PCA) and its influencing factors in Chinese patients before cataract surgery.

Patients and methods: A retrospective study was conducted in the First Affiliated Hospital of Soochow University, Suzhou, China. In all, this study enrolled 121 eligible eyes of 121 cataract patients. The astigmatism, aberrations and Q value of anterior, posterior and total cornea and anterior segment parameters (ACD, CCT, WTW, ATA) were measured by the Sirius System, and AL was measured by Lenstar LS 900. Cataract was diagnosed using slit-lamp examination.

Results: The mean age of patients was 67.44 ± 10.66 years old. Mean PCA was 0.31 ± 0.17 (range 0.05–1.09) D and 85.9% eyes had PCA values <0.5 D. With-the-rule (WTR) astigmatism predominated the anterior cornea astigmatism (ACA) (48.8%) and total corneal astigmatism (TCA) (61.2%), while against-the-rule (ATR) astigmatism predominated posterior (86.0%). Significant positive correlation was found between the astigmatic power vector (APV) of ACA and PCA (Pearson correlation=0.318, *P*<0.001); TCA and PCA (Pearson correlation=0.204, *P*=0.025); keratometric astigmatism and PCA (Pearson correlation=0.356, *P*<0.001); this study also found a positive correlation between primary spherical aberration (Z4°) of the total cornea and PCA (Pearson correlation=0.266, *P*=0.003); primary spherical aberration (Z4°) of the corneal front surface and PCA (Pearson correlation=0.260, *P*=0.004); total corneal aberrations (Total cornea root mean square [RMS]) and PCA (Pearson correlation=0.327, *P*<0.001); total corneal higher-orderaberrations (Total HOA RMS) (Pearson correlation=0.232, *P*=0.011); total corneal lower-order aberrations (Total LOA RMS) (Pearson correlation=0.250, *P*=0.006). A positive linear correlation between Q value of corneal front surface and PCA, either 6 mm pupil diameter (Pearson correlation=0.264, *P*=0.003) or 8 mm pupil diameter (Pearson correlation=0.184, *P*=0.043) was found in this study.

Conclusion: Corneal aberration, Q value (front surface specifically) was essential that we need to take into consideration when we conduct PCA and intraocularlens measurement in clinics.

Keywords: astigmatism, posterior corneal astigmatism, aberrations, Q value, Sirius, Scheimpflug photography

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Introduction

Cataract surgery has developed from blindness prevention surgery to refractive surgery. 30–54.9% of cataract patients have been found a corneal astigmatism of 1 diopter (D) or greater before surgery.[1–4] If this part of astigmatism is not treated, the

residual astigmatism after surgery will reduce the uncorrected visual acuity of patients, affecting the postoperative visual clarity. The anterior corneal surface has strong refractive power and is also the main component of corneal astigmatism. The posterior cornea surface was assumed to induce minimal refractive astigmatism,[5] hence only the anterior corneal surface was usually measured. Recent studies on total corneal astigmatism (TCA) however implicate both anterior and posterior corneal surfaces, suggesting potential astigmatic treatment calculation errors, if posterior corneal astigmatism (PCA) is disregarded.[6,7] Koch et al found TCA value is affected by PCA (average-0.3D).[8] PCA potentially decreased TCA in with-the-rule (WTR) astigmatism cases or increased it, as observed in against-the-rule (ATR) cases[1,8–10]; discounting PCA could result in miscalculated astigmatism, as in WTR cases overestimated by 0.5–0.6D and ATR underestimated by about 0.2–0.3D.[5] A 7.4°±10.3° axis error has also been documented, reportedly caused by ignoring PCA.[11] Therefore, the posterior corneal surface should also be considered, when evaluating the anterior surface, for astigmatism correction during cataract surgery.

With the advent of light path tracing, real TCA can be measured clinically, and PCA, which was often neglected before, has also been emphasized. Therefore, whether it is for intraocular lens (IOL) measurement or Toric IOL implantation calculation before surgery, it is essential to obtain accurate and personalized PCA before surgery. Corneal topography via Sirius imaging system involves a rapid, repeatable, non-contact, 360° rotational Scheimpflug camera, and a Placido-disk. Within seconds, the three-dimensional camera scans the lens, and maps the anterior and posterior corneal surface topography and elevation, which help with the depth, angle and volume analysis of the anterior chamber; the corresponding keratometer values deliver the wavefront analysis and pachymetric mapping of the entire cornea.[12–14] Parameters such as keratometry (K) value, central corneal thickness (CCT), anterior chamber depth (ACD), horizontal corneal diameter (WTW), angle to angle distance (ATA), astigmatism value, wavefront aberrations and Q value are obtained in one measurement. The Sirius Scheimpflug–Placido tomographer is routinely deployed in research as well as clinical use, and preceding studies that measured anterior segment parameters confirm high repeatability and reproducibility.[15,16] Its repeatability was similar to that reported for Pentacam.[17] Data that can be considered interchangeable between two instruments including the

simulated K; the posterior corneal power; the distance between the corneal endothelium and the Q value.[18]

Research has already substantiated PCA as significant to TCA, and in postoperative residual refractive errors as well, especially with reference to Toric IOL implanted patients. But posterior cornea characteristics, as influencing factors in cataract patients, still require thorough investigation. Hence, this research on Chinese cataract patients analyzes posterior cornea biometry in detail. It mainly analyzed the magnitude and axial distribution of PCA in middle-aged and elderly cataract patients, and the relationship between it and anteriorcornea astigmatism (ACA), TCA and simulated corneal astigmatism (keratometricastigmatism; KA), as well as the possible influencing factors such as age, axial length (AL), ACD, CCT, WTW, ATA, higher-order aberrations (HOAs) and Q value.

Patients and methods

This retrospective study recruited patients scheduled for cataract surgery, from July 31, 2017 to May 31, 2018, at the First Affiliated Hospital of Soochow University, Suzhou, China. Any patient with a history of glaucoma, uveitis, dry eye or corneal disease, who may have had ocular surgeries, or even wore contact lenses, within the preceding 2-week period was excluded.

The current research used the Lenstar (Lenstar LS 900, Haag-Streit AG, Koeniz, Switzerland) to measure the AL and Sirius (Sirius, CSO Inc, Florence, Italy) system to measure the ACA, PCA, TCA, KA, AL, ACD, CCT, WTW, ATA, aberration and Q value, all the astigmatism measurements were performed in zone 3 mm in diameter centered at the corneal center of the eyes, the aberration in pupillary areas of 6-mm analyzed included the root mean square (RMS) values of primary spherical aberration $(Z4°)$, primary coma aberration $(Z3^{1,−1})$, primary trefoil aberration $(Z3^{3,−3})$ of the total cornea, corneal front surface, and corneal back surface, total corneal aberrations (Total cornea RMS), total corneal lower-order aberrations (Total LOA RMS), total corneal HOAs (Total HOA RMS). The Q value includes the Q value of 6 and 8 mm pupil diameter on the anterior and posterior corneal surface.

Qualified doctors examined the subjects; the focus was on eliminating examiner bias. If measurements seemed beyond instruments limits, patients were re-examined as many times as necessary; excellent data and picture reproducibility ensured the most precise readings, which were then chosen for the study. ACA and TCA axis were

classified as WTR when the corneal surface steep meridian was 60–120° and ATR when 0–30° or 150–180°, corresponding to earlier studies. Conversely, with its characteristic negative posterior surface, PCA was specified as WTR with a 0–30° or 150–180° steeped meridian, and ATR for a 60–120° incline. Residual values classified as oblique astigmatism.

Vector astigmatism analyses were conducted using the method proposed by Thibos[19,20] for TCA, ACA, PCA and TA according to the following equations:

I) Vector along the $0-$ degree meridian $(J_0) = [-(\text{Ksteep} - \text{Kflat})/2] \times \cos 2\alpha$;

II) Vector along the $45-$ degree meridian $(J_{45}) = [-(\text{Ksteep} - \text{Kflat})/2] \times \text{sen} 2\alpha$;

III) Astigmatic power vector $(\text{APV}) = \left(J_0^2 + J_{45}^2\right)^{1/2}$.

The above-mentioned calculations were performed using Microsoft Excel (version 14.4.7; Microsoft Corporation, Redmond, WA, USA), after applying the astigmatism formula I), II), and III), J_0, J_{45} and APV are obtained, respectively.

Statistical analysis

This study used SPSS Statistics version 25.0 (IBM/SPSS, Inc., Chicago, IL, USA) for statistical analysis. Frequency (%), and mean and SD (mean ± SD) were respectively deployed for analyses of qualitative and quantitative variables. Pearson's correlation and regression analysis helped assess the TCA, ACA and PCA, aberrations, KA, age, Q value, CCT, ACD, AL, ATA and WTW correlations; statistical significance was set at $P \leq 0.05$.

Results

This study included a total of 121 eyes of 121 cataract patients, which qualified as per measurements. Table 1 summarizes the study of population demographics. The PCA mean value was set as 0.31±0.17D. ACA (69.4%) and TCA (64.5%) figures were predominantly <1.0D, while most PCA (57.0%) values ranged from 0.2 to 0.5D (Figure 1). The average axes of PCA were 77.65°±74.40°, 86.0% were ATR astigmatism, 8.3% were astigmatism with the rule, and the rest were oblique astigmatism (Figure 2). Unlike PCA, WTR astigmatism predominates the ACA (48.8%) and TCA (61.2%) (Figure 3).

Next, we studied the related factors of PCA, in this section, all astigmatisms and KA were evaluated by vector

analysis, the APV was calculated and a linear regression analysis presented ACA and PCA magnitudes as positively correlated (Pearson correlation=0.318, $P<0.001$); TCA and PCA (Pearson correlation=0.204, $P=0.025$); KA and PCA (Pearson correlation=0.356, $P<0.001$) (Figure 4).

PCA (Pearson correlation=0.266, $P=0.003$) positively correlated with total corneal primary spherical aberration (Z4°) as well; primary spherical aberration (Z4°) of the corneal front surface and PCA (Pearson correlation=0.260, $P=0.004$); total corneal aberrations (Total cornea RMS) and PCA (Pearson correlation=0.327, $P<0.001$); total corneal HOAs (Total HOA RMS) (Pearson correlation=0.232, $P=0.011$); total corneal LOA (Total LOA RMS) (Pearson correlation=0.250, $P=0.006$) (Figure 5). However, neither correlations were found between primary spherical aberration of the corneal back surface and PCA, nor primary coma aberration (Z3$^{1,-1}$), primary trefoil aberration (Z3$^{3,-3}$) of the total cornea, corneal front surface, and corneal back surface and PCA (Table S1).

Furthermore, we found a positive linear correlation between Q value of corneal front surface and PCA, either 6 mm pupil diameter (Pearson correlation=0.264, $P=0.003$) or 8 mm pupil diameter (Pearson correlation=0.184, $P=0.043$) (Figure 6); nevertheless, no correlations were found between Q value of corneal back surface and PCA (Figure 7).

This study also analyzed possible factors affecting PCA, including age, AL, ACD, CCT, WTW and ATA, but no correlation was found between them and PCA (Figure 8).

Discussion

With the increase of the proportion of the elderly and the increase of cataract surgery population, advanced functional IOL such as multifocal and triple-focus IOL and Toric IOL, the applications of which are becoming more and more widespread. PCA has often been neglected in the past clinical applications. But facts show that although the value is small, it is not a fixed value, that is, the distribution of PCA cannot be inferred only by measuring the asphericity of the anterior corneal surface.[21–23] Disregarding PCA potentially underestimates ATR astigmatism (ATRA) and overestimates WTR astigmatism (WTRA), and owing to the posterior surface's predominant WTR shape that affects the ATRA power, thus correspondingly yield an under-corrected ATRA and over-corrected WTRA.[7,10,24,25] The measurement errors of corneal refractive power and astigmatism before cataract surgery will lead to inaccurate IOL

Table 1 Demographics of study population

Parameter		
Eye/patient (n) Male/female (n)	121/121 58/63	
	Mean ± SD	**Range**
Age (years)	67.44±10.66	38–92
AL (mm)	24.64±2.47	21.17–31.94
ACD (mm)	2.72±0.38	1.83–3.75
CCT (mm)	0.54±0.03	0.48–0.62
WTW (mm)	11.35±0.38	10.50–12.44
ATA (mm)	11.53±0.76	9.88–15.38
PCA (D)	0.31±0.17	0.05–1.09
Axial	77.65±74.40	0–179
ACA (D)	0.87±0.64	0.08–3.42
Axial	84.61±51.73	2–178
TCA (D)	0.97±0.69	0.17–3.60
Axial	86.47±45.23	1–178
KA (D)	0.84±0.67	0.04–3.90
Axial	86.69±50.93	1–179
Q value 6 mm (A)	−0.10±0.17	−0.54–0.52
Q value 6 mm (P)	−0.41±0.30	−1.91±0.17
Q value 8 mm (A)	−0.28±0.14	−0.67±0.05
Q value 8 mm (P)	−0.40±0.20	−1.19±0.16
Z31,-1 cornea	0.37±0.21	0.03–1.06
Z33,-3 cornea	0.31±0.20	0.04–0.97
Z40 cornea	0.32±0.13	−0.06–0.80
Z31,-1 CF	0.39±0.20	0.02–0.97
Z33,-3 CF	0.34±0.22	0.00–1.11
Z40 CF	0.30±0.14	−0.14–0.80
Z31,-1CB	0.09±0.05	0.02–0.26
Z33,-3CB	0.07±0.06	0.01–0.38
Z40 CB	0.02±0.03	−0.04–0.14
Total cornea RMS	1.14±0.60	0.49–3.97
Total HOA RMS	0.82±0.65	0.07–3.94
Total LOA RMS	0.69±0.28	0.32–2.00

Notes: Q value 6 mm (A) = Q value of anterior corneal surface under 6 mm pupil diameter, Q value 6 mm (P) = Q value of posterior corneal surface under 6 mm pupil diameter, Q value 8 mm (A) = Q value of anterior corneal surface under 8 mm pupil diameter, Q value 8 mm (P) = Q value of posterior corneal surface under 8 mm pupil diameter, Z31,-1 cornea = the primary coma aberration of the total cornea, Z33,-3 cornea = primary trefoil aberration of the total cornea, Z40 cornea = primary spherical aberration of the total cornea, Z31,-1 CF = primary coma aberration of the corneal front surfaces, Z33,-3 CF = primary trefoil aberration of the corneal front surfaces, Z40 CF = primary spherical aberration of the corneal front surfaces, Z31,-1 CB = primary coma aberration of the corneal back surfaces, Z33,-3 CB = primary trefoil aberration of the corneal back surfaces, Z40 CB = primary spherical aberration of the corneal back surfaces, Total cornea RMS = the total corneal aberrations, Total HOA RMS = total corneal higher-order aberrations, Total LOA RMS = total corneal lower-order aberrations.
Abbreviations: AL, axial length; KA, simulated corneal astigmatism; ACA, anterior cornea astigmatism; ACD, anterior chamber depth; AL, axial length; APV, astigmatic power vector; ATA, angle to angle distance; ATRA, ATR astigmatism; CCT, central corneal thickness; D, diopter; HOAs, higher-order aberrations; IOL, intraocular lens; K, keratometry; LOA, lower-order aberrations; PCA, posterior corneal astigmatism; RMS, root mean square; TCA, total corneal astigmatism; WTR, with-the-rule; WTRA, WTR astigmatism; WTW, horizontal corneal diameter.

degree in surgery. Especially before Toric IOL implantation, the determination of degree and axis should be combined with the required spherical lens degree, corneal astigmatism value and axis to calculate. The wrong choice of corneal astigmatism will make the model and axis of IOL mismatch with the actual corneal astigmatism. This will inevitably lead to postoperative refractive errors, affecting the visual experience of people after cataract extraction. Therefore, in order to achieve better effect of astigmatism correction, PCA should be quantitatively analyzed when we perform ocular biometry before surgery. With the development of anterior segment examination equipment, there are many kinds of anterior segment analyzers that can directly quantify PCA, such as Pentacam, Orbscan and Sirius. In this
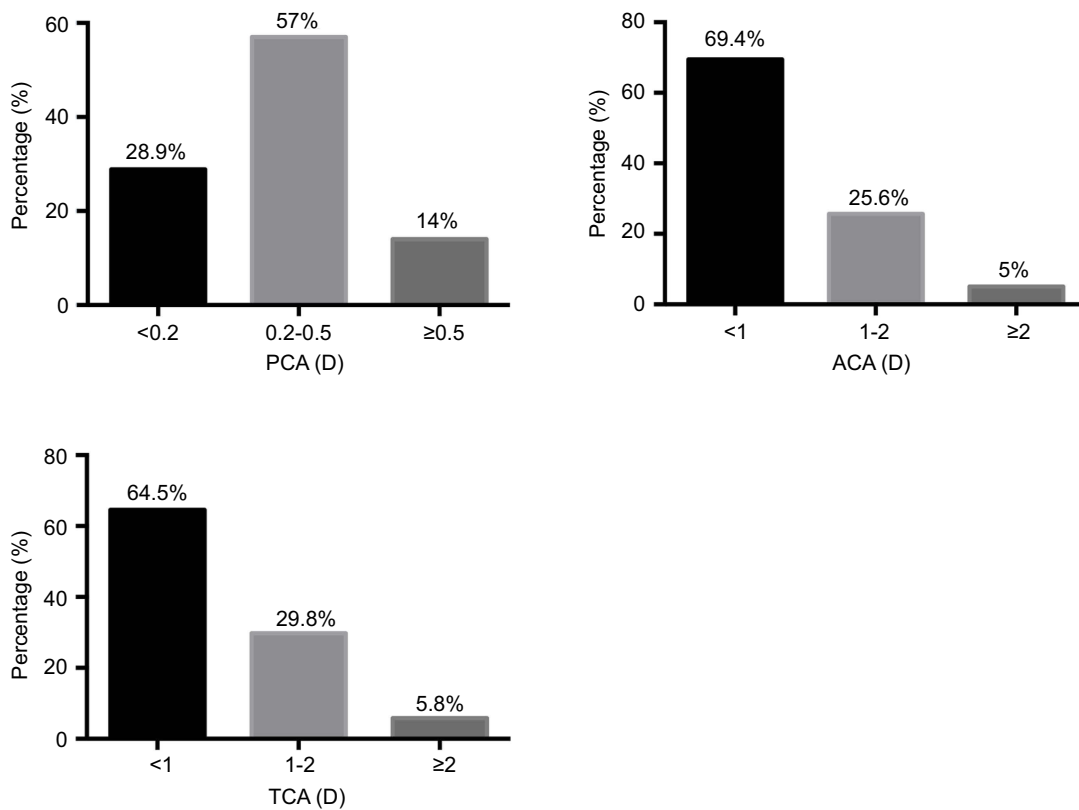
Figure 1 Distribution of magnitude of PCA, ACA and TCA at 3-mm corneal diameter in cataract patients.
Abbreviations: D, diopters; PCA, posterior corneal astigmatism; ACA, anterior corneal astigmatism; TCA, total corneal astigmatism.
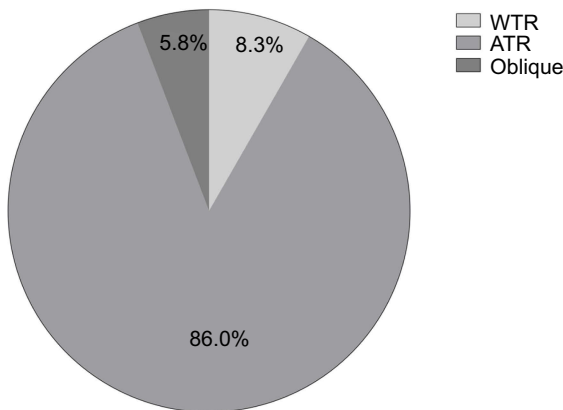

Figure 2 Distribution of axial of PCA at 3-mm corneal diameter.
Abbreviations: PCA, posterior corneal astigmatism; WTR, with-the-rule; ATR, against-the-rule.
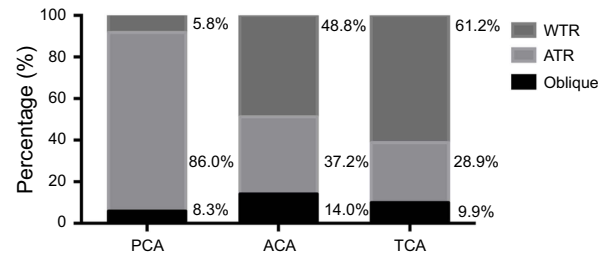

Figure 3 The overall distribution of anterior, posterior, and TCA at 3-mm corneal diameter in cataract patients.
Abbreviations: PCA, posterior corneal astigmatism; ACA, anterior corneal astigmatism; TCA, total corneal astigmatism; WTR, with-the=rule; ATR, against-the-rule.

study, Sirius anterior segment analysis system was used to calculate the total corneal refractive power, TCA, simulated corneal astigmatism, anterior and posterior surface astigmatism, and so on by light path tracking. PCA can be quantitatively analyzed with high repeatability.[15,26,27]

Wavefront aberration is usually fitted on a specific circular domain. When a specific circular domain changes, the fitted wavefront aberration will also change. Therefore, pupil size plays an important role in the estimation of wavefront aberration. The visual quality is mainly affected by aberration and astigmatism. When the pupil size is <3 mm, the aberration is very small. The aberration is generally <1/4th of the wavelength of light. Therefore, when the pupil size is in this area, the image quality of the retina is usually not disturbed by aberration and scattering.[28] With the increase of pupil size, aberration will also increase gradually. At this time, the pupil size becomes
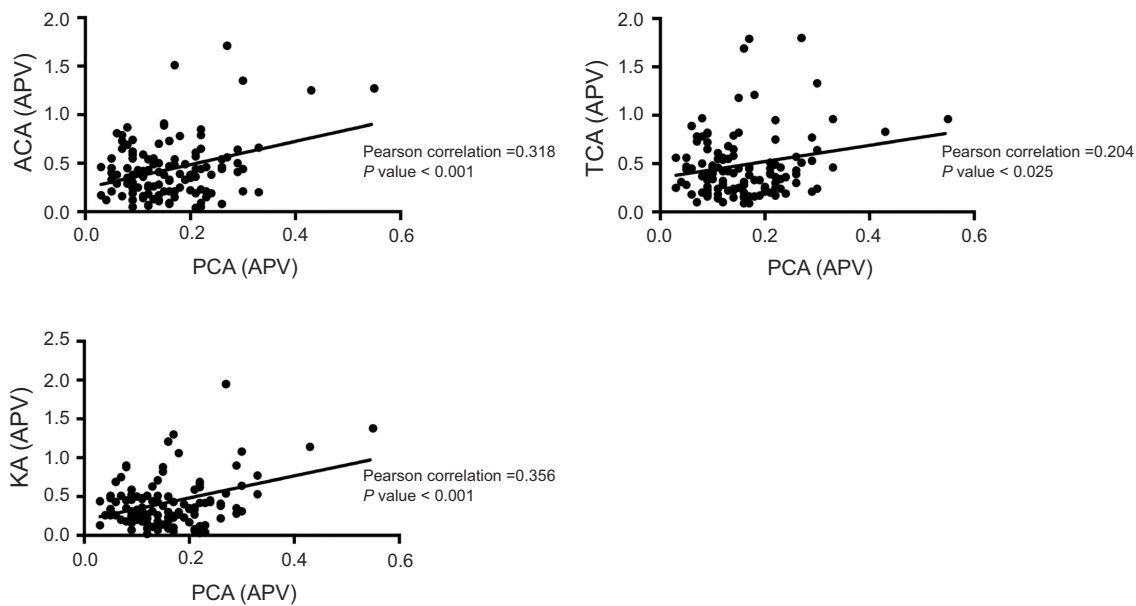
Figure 4 Positive linear correlations between the magnitude of ACA, TCA, KA and PCA.
Abbreviations: PCA, posterior corneal astigmatism; ACA, anterior corneal astigmatism; TCA, total corneal astigmatism; KA, simulated corneal astigmatism; APV, astigmatic power vector.

the main factor affecting aberration. In addition, pupil size is a factor that could affect visual function in eyes with refractive error, because of the amount of the aberrations, not only HOAs but also LOAs, are correlated with pupil diameter. Kamiya et al[29] posit that the magnitude of astigmatism and pupil area size is a determining factor in uncorrected distance visual acuity (UDVA) in normal young phakic eyes. In vision systems with abnormalities (including both normal and pseudophakic eyes), optical quality is reduced in direct proportion to the diameter of the patients' pupils. Watanabe et al[30] found that after cataract surgery, the postoperative UDVA was moderately negatively correlated in eyes with ATR astigmatism irrespective of the pupil size, and that UDVA was moderately negatively correlated in eyes with WTR astigmatism only when the pupils were large. Our study was performed using a 6.0 mm pupil scan diameter, which is widely used to evaluate optical aberrations. Senile miosis and lower defocus sensitivity in systems with ocular HOAs may mitigate such abnormalities.[31] Pseudophakic eyes are expected to allow for better vision than phakic eyes due to the abnormalities being mitigated by smaller pupil diameters in older patients.[31] In light of this finding, a wider range of IOL choices would be tolerated in elderly patients, allowing surgeons to consider safety factors and potential complications more carefully.

Studies have often focused on the effects of PCA on total astigmatism[32–34] and Toric IOL previously.[5,35] However, little is known about the influencing factors of PCA, especially the relationship between PCA and HOAs and Q value of cornea. Therefore, this study extensively focuses on PCA in Chinese cataract patients.

Some studies have found that the PCA of the cornea is 0.26–0.78 in most corneas and the steep axis is located in the vertical diameter line, which produces reverse astigmatism.[10,11] Koch[10] found that 9% of eyes had astigmatism >0.50 D. Jiang[36] also found 87.04% eyes had PCA values <0.5 D, 12.96% eyes in Chinese cataract patients had PCA ≥0.5 D, ATR astigmatism predominated PCA (85.4%). In this study, the posterior corneal surface astigmatism averaged 0.31±0.17 D, wherein 86.0% was ATRA, 8.30% was WTRA, and 85.9% presented PCA <0.5 D, consistent with the preceding results,[10,11,36] submitting a fairly stable PCA magnitude; direct measurement was not possible earlier, hence, our study essentially estimates TCA and PCA aspects, as do several other ongoing analyses, to supplement previous findings.

The current study found ACA and PCA to be significantly correlated; thus consistent with earlier studies again,[10,37,38] PCA exhibited a strong positive correlation with KA and correlated weakly with TCA. These findings are vital to clinical practice and indicate high ACA values in eyes usually signify high PCA values as well, affecting
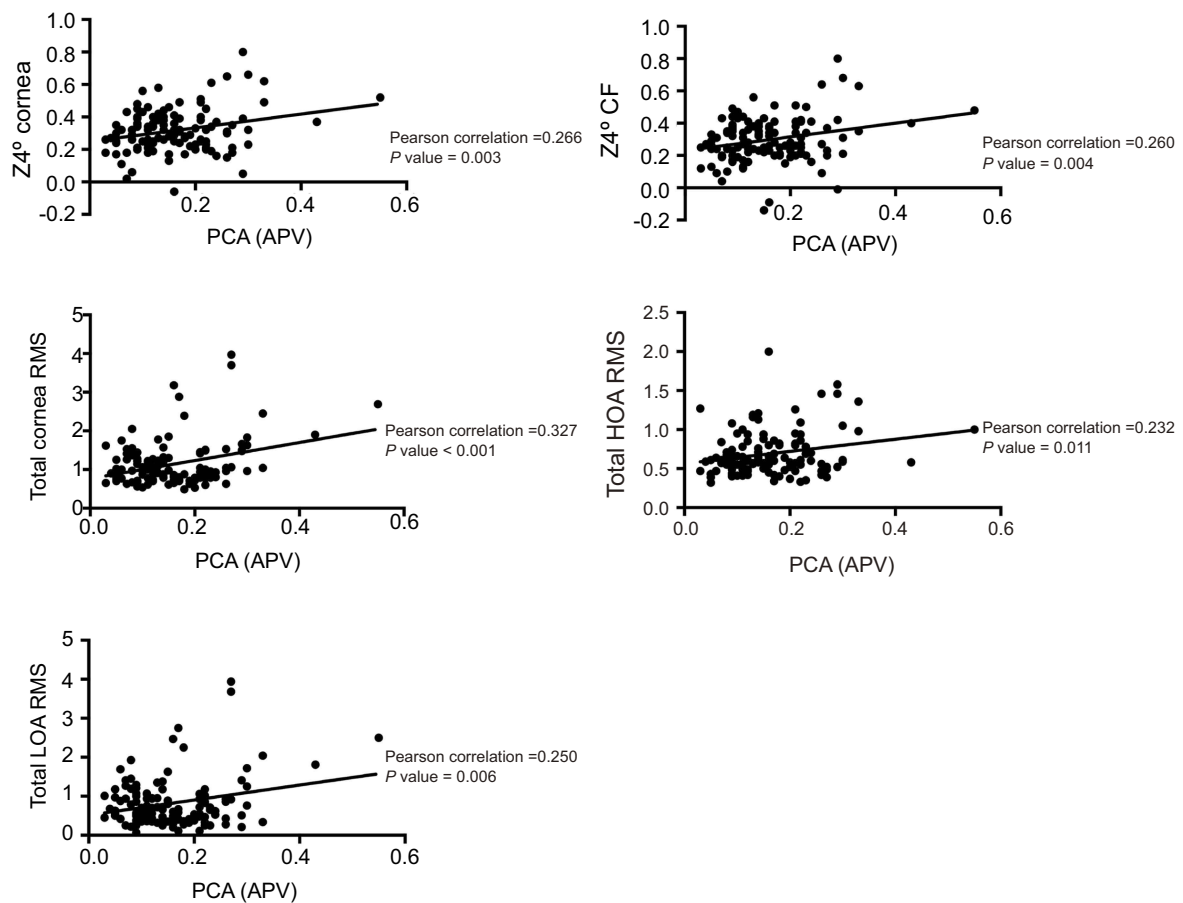
Figure 5 Positive linear correlations between the corneal aberration and PCA.
Abbreviations: Z4° cornea, primary spherical aberration of the total cornea; Z4° CF, primary spherical aberration of the corneal front surface; Total cornea RMS, total corneal aberrations; Total LOA RMS, total corneal lower-order aberrations; Total HOA RMS, total corneal higher-order aberrations; RMS, root mean square; APV, astigmatic power vector.

total corneal biometry. Therefore, when selecting IOL individually before cataract surgery, especially Toric IOL astigmatism evaluation, we should not only evaluate ACA, TCA or KA, but also include PCA in routine evaluation. For some primary hospitals without PCA instruments, it is suggested to observe ACA, TCA or KA to judge the magnitude of PCA. The relationship between them needs to be further studied for clinical application.

Previous studies have confirmed that corneal astigmatism is positively correlated with HOAs.[39,40] It is also correlated with some components of corneal HOA, such as coma aberration and trefoil aberration.[39,41] However, the relationship between PCA and corneal aberration has rarely been reported before. After analyzing the correlation between PCA and corneal aberration, we found that PCA was positively correlated with primary spherical aberration of the total cornea, primary spherical aberration of the corneal front, total corneal aberration, high-order corneal aberration and low-order corneal aberration (LOA).

However, it has no significant correlation with other components of HOAs such as coma aberration and trefoil aberration, which indicates that with the increase of PCA value, corneal spherical aberration, total corneal aberration, HOA and LOA will also increase, which may be related to the decrease of retinal imaging quality caused by HOA caused by astigmatism.[42] Spherical aberration is the fourth-order HOA, which is the main aberration affecting vision in HOA of cornea.[43] It is also the only axisymmetric HOA that can be corrected by IOL.[44] At present, the application of aspheric IOL compensates the corneal spherical aberration and improves the visual function after cataract surgery. The visual quality of patients after surgery is mainly related to the residual aberration after implantation of aspheric IOL.[45] Our results show that PCA is positively correlated with spherical aberration, suggesting that preoperative PCA assessment is also important for cataract patients to choose appropriate IOL. HOAs are closely related to visual quality,[46,47] contrast
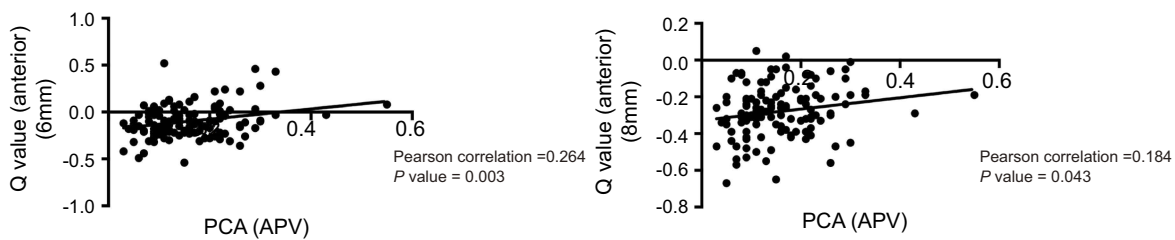
Figure 6 Positive linear correlations between the Q value (anterior) and PCA.
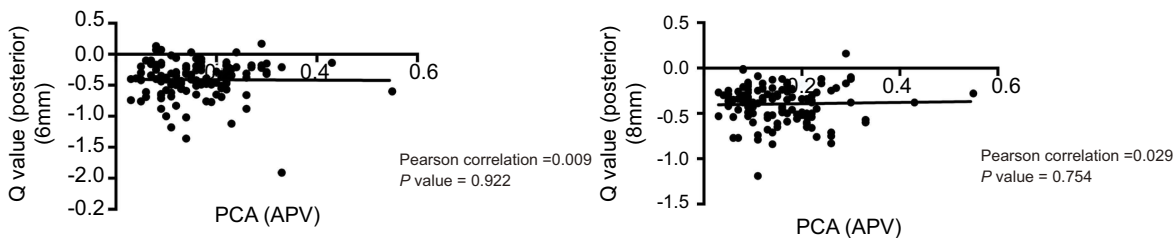**Abbreviations:** PCA, posterior corneal astigmatism; APV, astigmatic power vector.

Figure 7 Correlations between the Q value (posterior) and PCA.
Abbreviations: PCA, posterior corneal astigmatism; APV, astigmatic power vector.

sensitivity,[48] visual symptoms[49] and visual efficacy.[50] Our results show that PCA is correlated with HOA, especially spherical aberrations. Preoperative evaluation of PCA before cataract surgery will be of great significance to the recovery of visual function after surgery and to the better visual effect of patients.

The curvature of the anterior surface of normal cornea is different from the apex to the periphery, which belongs to aspheric surface. The non-spherical shape of cornea helps to reduce the aberration caused by light passing through the surrounding cornea when the pupil is dilated and improve the visual quality. At present, the aspheric coefficient of cornea (Q value) is commonly used to describe the changing trend of corneal curvature from the center to the periphery and to quantify the aspheric degree for comparison.[51,52] Studies have shown that the effect of changes in Q value of cornea on HOAs may be one of the main causes of visual quality deterioration in some patients after corneal refractive surgery.[53,54] Accordingly, Q-guided individualized keratectomy was proposed. According to different target Q value of each patient, cornea is cut to keep the Q value of cornea relatively unchanged after surgery, reduce the HOA caused by surgery, and improve the visual quality of patients after surgery.[55] Therefore, we studied the correlation between PCA and Q value of cornea and found that PCA was positively correlated with Q value of anterior corneal surface under 6 and 8 mm pupil diameter, but not with Q

value of posterior corneal surface. This result can be explained by the relationship between the Q value of cornea and the spherical aberration of anterior surface. Antonio[56] summarized the relationship between corneal anterior surface spherical aberration and corneal Q value by using corneal model system. If the corneal refractive index and pupil diameter remain constant, the flatter the corneal surface (the smaller the Q value), the smaller the spherical aberration, and the steeper the corneal surface (the larger the Q value), the greater the spherical aberration. As previous studies have shown, PCA is mainly related to the anterior surface spherical aberration, but not to the posterior surface spherical aberration, so it is not difficult to understand that PCA is only related to the anterior surface corneal Q value. This result provides a theoretical basis for designing an aspheric artificial lens according to the Q value of cornea and improving the imaging quality.

Earlier studies established PCA had a weak negative correlation with age, and younger patients presented a higher mean PCA, as compared to the older ones.[57] Nevertheless, further research submitted that, with increasing age, the posterior corneal surface usually remained the same, notably because of a relatively unchanged posterior steep meridian (a WTR to ATR shift marked the anterior and total meridians).[10,45,58] In our study, no correlations were found between PCA and age, which may be related to the research population. Our study focused mainly on
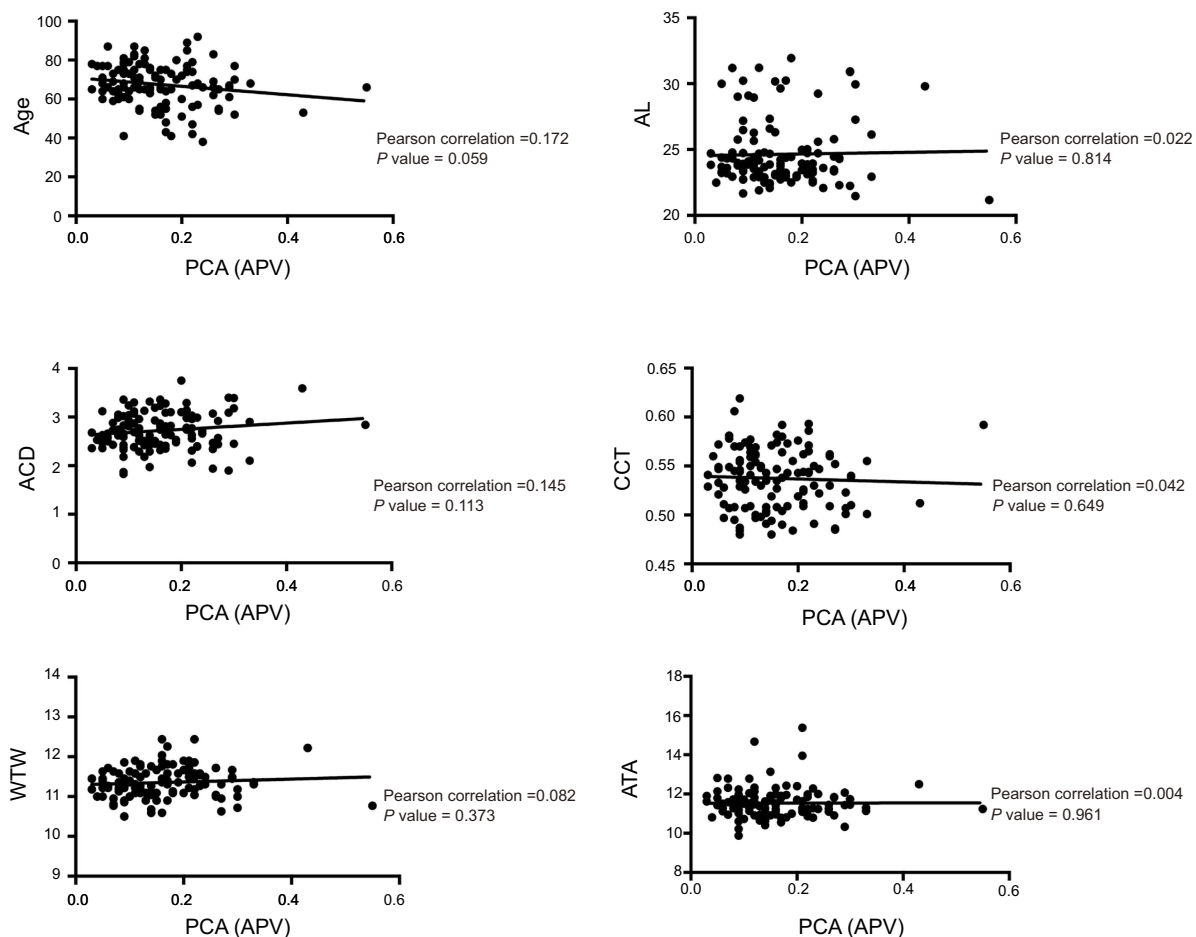
Figure 8 Correlations between Age, AL, ACD, CCT, WTW, ATA and PCA.
Abbreviations: PCA, posterior corneal astigmatism; AL, axial length; ACD, anterior chamber depth; CCT, central corneal thickness; WTW, horizontal corneal diameter; ATA, angle to angle distance; APV, astigmatic power vector.

middle-aged and the elderly, suggesting that PCA has little change in the middle-aged and the elderly cataract patients. Previous studies have found that there is no significant difference in the distribution of PCA values and astigmatism types between high myopia group and control group, which means that PCA values and astigmatism types are relatively stable, and will not change with the change of AL. In addition, Kaye[58] found that although the total astigmatism of the eye is related to the myopia degree, the corneal astigmatism is not related to the myopia degree. Moreover, the increase of vitreous cavity length plays a major role in the development of myopia.[59] These two points can explain why PCA does not change with AL. This study is consistent with previous studies in that no correlation between PCA and AL has been found.

In addition, this research also observed the relationship between PCA and ACD, CCT, WTW and ATA, which was rarely reported in previous studies, but PCA was not found

to be significantly correlated with these factors. It shows that PCA degree is relatively stable, and these factors seems negligible when evaluating PCA.

The current study has some limitations. Firstly, our study sampled only a small number of patients, and secondly, we only deployed Sirius, results should have been confirmed via other corneal imaging techniques as well. Nevertheless, the device demonstrated exceptional repeatability, when measuring both corneal astigmatism, and aberrations.

Conclusion

In summary, our study showed that compared with ACA and TCA, the magnitude of PCA is small and most of them are ATR astigmatism. Posterior surface astigmatism is significantly and positively correlated with anterior surface astigmatism and total astigmatism. PCA is positively correlated with whole corneal spherical aberration, anterior

surface Q value, anterior surface spherical aberration, whole corneal aberration, total high-order aberration and total low-order aberration, but not with age, AL, ACD, CCT, WTW and ATA. Consequently, clinical measurement of corneal astigmatism and IOL should essentially factor the corresponding aberration and Q value (front surface specifically).

Ethics approval and informed consent

The study protocol adhered to the tenets of the Declaration of Helsinki and was approved by the institutional review board of the First Affiliated Hospital of Soochow University. All patients signed an informed consent to allow the retrospective evaluation of their clinical data.

Consent for publication

Written informed consents were obtained to publish the details from each participant.

Data availability

Available upon request.

Disclosure

The authors report no conflicts of interest in this work.

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Supplementary material

Table S1 Correlations between PCA and influencing factors

PCA (APV)	R	R^2	P
Age	−0.172	0.030	0.059
AL	0.022	0.000	0.814
ACD	0.145	0.021	0.113
CCT	−0.042	0.002	0.649
WTW	0.082	0.007	0.373
ATA	0.004	0.000	0.961
$Z3^{1, -1}$ cornea	0.156	0.024	0.088
$Z3^{3, -3}$ cornea	0.112	0.012	0.223
$Z3^{1, -1}$ CF	0.161	0.026	0.078
$Z3^{3, -3}$ CF	0.085	0.007	0.356
$Z3^{1, -1}$ CB	0.015	0.000	0.867
$Z3^{3, -3}$ CB	−0.036	0.001	0.693
$Z4°$ CB	−0.004	0.000	0.966
Q value (posterior 6 mm)	−0.009	0.000	0.922
Q value (posterior 8 mm)	0.029	0.001	0.754

Abbreviations: PCA, posterior corneal astigmatism; AL, axial length; ACD, anterior chamber depth; CCT, central corneal thickness; WTW, horizontal corneal diameter; ATA, angle to angle distance; APV, astigmatic power vector.